PcT

Report No. 89

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
HELIUM ACTIVITY
HELIUM RESEARCH CENTER

INTERNAL REPORT

PRESSURE MEASUREMENTS AND VOLUMETRIC MATERIAL BALANCE

CORRELATIONS FOR THE CLIFFSIDE HELIUM STORAGE RESERVOIR

BY

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BRANCH Fundamental Research

PROJECT NO. 4912

DATE May 1966

AMARILLO, TEXAS

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* Because of their extensive nature, all illustrations and tables are found at the end of this report just preceding the list of references.

PRESSURE MEASUREMENTS AND VOLUMETRIC MATERIAL BALANCE CORRELATIONS FOR THE CLIFFSIDE HELIUM STORAGE RESERVOIR

by

R. A. Guereca[1] and H. P. Richardson[2]

ABSTRACT

This report summarizes electronically measured wellhead pressures at Bush A-5 in the presently closed-in area of the Cliffside helium storage reservoir and makes an estimate of the reaction time to production from opening-up Bush A-9 in the same area. Also, deadweight wellhead pressure measurements from Bush A-5 and five other closed-in wells are presented. After conversion of pressures to absolute pressures at the arbitrarily selected zero subsea datum, data trends are discussed from a short-range and long-range time basis. A volumetric material balance - pressure maintenance estimate is presented to qualitatively relate the arithmetic average pressure of all wells with injection - production statistics for the entire reservoir. Qualitative data trends are discussed by comparing changes in slope of pressure from pressure-time data for all wells assuming straight line, least square

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Work on manuscript completed May 1966.

deviations. Conclusions and recommendations are made to serve as guidelines for future work, especially regarding electronic measurements.

INTRODUCTION

The original intent of this work, actually started during the last two weeks of November 1965, was to electronically follow wellhead pressure fluctuations in a closed-in well, Bush A-5, to within 0.1 psi on a practically continuous basis; during these measurements, a neighboring closed-in well, Bush A-9, would be opened-up to production. As pressure data accumulated, it became evident that an attempt should be made to correlate all closed-in wellhead pressures with injection - production statistics for the entire gas storage reservoir. This report presents the electronically measured pressures at Bush A-5, deadweight tester pressure measurements at Bush A-5 and five other closed-in wells in the same reservoir, and injection - production volumetric material balance qualitative correlations.

The Bush Dome Cliffside helium storage reservoir contains 11 gas producing wells, two gas injection wells, and five observation wells; one of the observation wells, Bivins A-8R, was drilled 50 feet into the caprock of the storage reservoir and completed in the overlying Red Cave formation. The other four observation wells are completed in the storage reservoir. Bush A-2, Bush A-3, and Bush A-5 are gas withdrawal wells which have been invaded by stored helium. Based on core analyses, the average porosity and permeability of the brown dolomite

cores are 12 percent and 10 millidarcies, respectively; laboratory analysis shows that the main constituents of the in-place gas are methane (about 67 percent), ethane (4 percent), propane (2 percent), nitrogen (24 percent), and helium, about 1.8 percent (3).[3] The injected conservation helium-gas mixture is approximately a 70-30 percent helium-nitrogen mixture.

Two months prior to the beginning of this study, eight wells had been closed-in for stabilization purposes; that is, the attainment of a steadily increasing pressure level with a steadily increasing ratio of gas injected to gas produced. The eight closed-in wells, figure 1,[4] are all located in the northerly section of this very tight reservoir. It is believed that the closed-in period was sufficient for the measured static wellhead pressures to reflect bottom-hole pressures. From December 1963 through September 1965, 11.37 billion standard cubic feet of helium-gas mixture was injected and 8.73 billion standard cubic feet of gas was produced; this gas injected to gas produced ratio, 1.30, was sufficient to increase the reservoir pressure from about 674 pounds per square inch absolute (psia) to 693 psia by August 1965. During September 1965, the injected - produced gas ratio was 1.76. From October 1965 through February 1966, 2.319 billion standard cubic feet of gas was injected and 1.174 billion standard cubic feet of gas was produced, or the injected to produced ratio was 1.98 which, on an overall basis,

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[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

[4] Because of their extensive nature, all illustrations and tables are found at the end of this report just preceding the list of references.

should have been reflected by a general, although not necessarily steady, increase in the reservoir pressure level. In a later section, it will be shown by volumetric material balance methods what the injected - produced ratio should be to at least maintain the pressure at 693 psia. It should be mentioned that the helium content of Bush A-5 had gone to 5 percent when it was last sampled in August 1965. The helium content in Bush A-3 and Bush A-2 has gone to 3 and 13.3 percent, respectively.

ACKNOWLEDGMENT

For their assistance and cooperation throughout this study, especially in obtaining deadweight tester pressure measurements and injection - production data, the authors are indebted to field and engineering personnel of the Division of Helium Resources, Helium Activity, Bureau of Mines, Amarillo, Texas.

ELECTRONIC PRESSURE MEASURING APPARATUS

Of the four methods discussed in Memorandum Report No. 76 (2), "Method A", utilizing a pressure level transducer at the wellhead, was used because of the practicality of first developing a static wellhead technique. Simply stated, the pressure in pounds per square inch gage (psig) was converted to an electrical signal which was digitally printed on a paper tape; figures 2A, 2B, and 2C show front, back, and outside views of the apparatus and the meter house at Bush A-5. The basic unit for the mechanical to electrical conversion was a Teleflight[5] Model

[5]Trade names are used for information only and endorsement by the Bureau of Mines is not implied.

185-SA pressure level transducer. Under nominal laboratory conditions, temperature and line voltage fluctuations are insignificant; however, with the extreme conditions expected in the field, control of the temperature environment and line voltage was required.

For the field installation, and 8- by 8-foot sheet-metal building, subsequently insulated with commercial Fiberglas, was spotted about 20 feet from the well site. A 1/4-inch copper line from the wellhead in the concrete cellar was laid in an earth-covered trench from the wellhead to the inside of the building. Electrical power was provided by a Wolverine Power Company gasoline generator set of 120-volt, 60-cycle, 9.4 kilowatts capacity. Two power lines were run into the building, one was regulated and the other unregulated.

The temperature in the building was controlled to 85°±1° F during normal operation. This was accomplished with unregulated power using a Leeds and Northrup No. 6254 Electromax temperature controller. A set-point, resistance-bridge balance was established within the controller and an external resistance sensor arranged to detect any temperature drop. This caused the actuation of relays which started three electrically-operated heater-blowers of about 2,000 watts each. Two supplementary blowers were operated continuously to minimize temperature gradients in the building. As the temperature increased to the set point, the controller would turn the heaters off. The temperature in the building was monitored using a Yellow Springs Instrument Company Tele-Thermometer. The output was recorded on a Moseley Autograph No. 600 stripchart recorder. The chart rate was set at one division per

hour or approximately one inch per hour, thus temperature anomalies could be correlated with pressure readings.

The electronic readout equipment was not sensitive to small power-line voltage fluctuations; however, large and continuous over- or under-voltages would cause damage. To minimize this, a voltage protection circuit[6] was incorporated to shut off current to the electronics if the voltage varied outside the limits of 105 to 125 volts. The unit was placed in the regulated power line. Pressure measurement was accomplished using the aforementioned Teleflight transducer. This unit uses the unknown pressure to proportionally and precisely strain a metal diaphragm; this strain is physically transmitted to a sensor that changes resistance with a direct relation to strain. The resultant change in resistance due to pressure is utilized in a Wheatstone bridge arrangement to provide an output signal that also is related to the unknown pressure.

The Wheatstone bridge arrangement incorporated in the transducer requires an external source of power. A highly regulated and stable direct current source of 10 volts (nominal) was provided by an Evenvolt Model 209-N power supply. This voltage was continually monitored by a Non Linear Systems No. 481 digital voltmeter. It also should be noted that the transducer output is directly related to the magnitude of the input power. Both transducer and power supply are critical compon-

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[6] J. R. McVey, Electronic Technician, Helium Research Center, Bureau of Mines, Amarillo, Texas, designed this circuit and contributed substantially to the proper functioning of the electronics.

ents and are sensitive to temperature changes; to give added validity to the data, both were placed in an oven, regulated to 85°±1° F, in a rack module that held the readout equipment.

After the pressure was introduced into the transducer, the 10-volt nominal, 9.779 actual, power was applied to the electrical circuit. At this time a millivolt potential of 0-30, corresponding to 0-1,000 psig, appears at the output terminals of the transducer. This value could have been used, with suitable mathematical conversion, to yield pressure if a satisfactory digital voltmeter had been readily available. However, since this was not the case, the signal was converted electronically to a digital pressure reading in psig by a Vidar Instrument Company No. 260 voltage-to-frequency converter which incorporates a variable amplifier-output attenuator. With this unit, the millivolt output was converted to a sine-wave frequency at a nominal 3.33 kilocycles per millivolt of potential. This frequency was then fed into a Beckman/Berkeley EPUT electronic counter or frequency meter where the frequency was displayed in cycles per second. As this value was displayed, an integrally attached printer of the same manufacturer printed the value on paper tape.

To correlate these readings with time and temperature and to minimize paper consumption, a time switch was placed in the print-command signal-line. This allowed continuous operation of the frequency meter but only allowed printing for about three minutes of each hour on the hour.

As it was desirable to have a reading accuracy of 0.1 psi and a resolution of 0.01 psi, it was necessary to calibrate the complete system to determine the parameters accurately instead of nominally. This was done in the laboratory using a Ruska deadweight gage that is accurate to 0.01 percent or better. Incremental changes of 10 psi at 600 and 700 psig were reflected in the readout with an accuracy of 0.085 psi. The readout was monitored constantly for 17 minutes while the deadweight gage was held carefully at a constant 650 psig; variation in the output was less than 0.005 psi. Based on the above, it was concluded that the readings, at controlled laboratory conditions, were well within the desired accuracy and reproducibility.

Nominally, a one-millivolt output of the pressure transducer corresponds to 33.33 psig; for the voltage-to-frequency converter, one millivolt corresponds to 3.33 kilocycles. Nominally, then, one kilocycle corresponds to 10 psig or 100 kilocycles correspond to 1,000 psig. The variations of the outputs of both the transducer and converter are less than 0.01 percent per degree at fullscale from about 70° to 105° F. When the input pressure is of the order of 650 psig into the transducer, its output accuracy is 0.065 psi; the accuracy of the converter is practically the same. If both errors of 0.065 operate in the same direction, the accuracy of the measurements should be at least 0.13 psig since the accuracy of the electronic counter is 0.2 parts per million, according to the manufacturer.

In the actual laboratory calibration, discussed above, the experimentally determined accuracy was 0.085 psig, which is somewhat better

than the assumed 0.13 psig just mentioned; at the field installation the precision or reproducibility was no better than 0.02 psi as indicated by the printout tapes.

DEADWEIGHT TESTER PRESSURE DEVICE

Deadweight pressures for Bush A-5 and five other closed-in wells were obtained with a portable Refinery Supply 9020 deadweight tester. The range of this instrument is to 1,000 psig at 0.1 psi intervals and requires adding the corresponding barometric pressure for absolute pressures. Its accuracy is capable of being determined, as claimed by the suppliers, to 0.1 percent of the indicated pressure corresponding to 0.6 psig at the level of the pressures measured. The device was calibrated in the laboratory against the 0.01-percent accurate Ruska deadweight gage and found to be reading about 2 psi high; the precision, however, was found to be 0.1 psi at a given pressure and temperature level. No attempt was made to correct the deadweight measurements to the more accurate Ruska values since absolute pressure levels were not the main parameters of interest; for this report, the changes of pressure with time are more pertinent. Over a long period of time, one to two months, they do show the general trend of the pressure variations of wells in the stabilization area of figure 1 and are reported to 0.1 psi.

ABSOLUTE PRESSURE TO A COMMON DATUM

Static wellhead pressures in the closed-in or stabilization area were converted to the arbitrarily selected zero subsea datum plane

because: (1) sufficient time had elapsed so that closed-in wellhead (WH) pressures should reflect static bottom-hole (BH) or static reservoir pressure; (2) of the need to take into account the different well elevations and perforation midpoints; (3) the well bores, except Bush A-5 and Bush A-2, are essentially filled with in-place 1.8 percent helium Cliffside gas; (4) of the availability of experimental data to compute gas gradients; and (5) of the greater significance of BH pressures in reservoir behavior trends as pointed out by Pirson (5).

The average reservoir temperature is about 92° F and, as of August 1965, the average reservoir pressure was about 693 psia, according to information supplied by Division of Helium Resources personnel. At these reservoir conditions, the interpolated, least square, compressibility factor, Z, for the in-place gas was calculated to be 0.9348 from the work of Carroll and Churchwell (1); based on an average molecular weight, $\bar{M}$, of 21.095 the computed density is 2.645 pounds per cubic foot using the relation density equals $P\bar{M}/ZRT$ (in engineering units as shown on page 20 of this report). The average molecular weight of 21.095 was calculated from the average field gas analysis shown in Holmes' report (3).

Table 1 summarizes well-gradient corrections to be added to the wellhead pressures to obtain absolute pressures at the zero subsea datum. No claim is made as to the absoluteness of these pressures since, at the present time, it is not known to what degree the reservoir is in communication within itself. However, as the last column of table 1 shows, the well gradients are different and need to be

taken into account when comparing pressure changes and estimating reservoir behavior trends. Actually, a more realistic datum plane is +50 feet subsea; this, however, will not affect the pressure changes or gradients discussed in this report.

DISCUSSION OF PRESSURES AT BUSH A-5

As indicated above, the transducer wellhead pressures should be accurate to 0.1 psig and actually were reproducible to about 0.02 psi. The accuracy of the deadweight tester measurements at Bush A-5 (and five other closed-in wells) probably is no better than 2 psig. However, deadweight values should be precise to 0.1 psi for any given measurement and are presented to this value to show general data trends, especially on a long-range time basis. The electronic values are believed to be very indicative, especially on a short-range time basis. Further, it is not intended to compare the electronic to the deadweight values, point-by-point.

December 1965 - March 1966

Table 2 summarizes transducer values from December 3, 1965, to March 11, 1966. In general, the wellhead pressures shown are averages, usually from about midnight to five in the morning when the temperature in the meter house was generally most constant. In fact, the trend of a large proportion of the temperature charts showed a "diurnal" effect in that the temperature started increasing steadily at about 10 am and reached a maximum about 3 pm when it started decreasing slowly and more-or-less settled down about 8 pm.

In general, every hour an average of 10 values was printed within three minutes; these were averaged for the hour. The next hour another 10 values were recorded and averaged, etc. The 638.48 shown for December 3 represents the overall average for an 8-hour period when the temperature was holding steady according to the temperature recorder chart. The barometric pressure shown was the field value used the same day to obtain the wellhead pressure in psia with the deadweight tester.

On Saturday, December 4, when no deadweight measurement was taken, the barometric pressure shown was obtained by reading a barometer chart at the Helium Research Center and correcting it to the field. For example, on January 13 at 10 am the field barometric pressure was 13.1 when the deadweight measurement was taken. The Research Center chart read 26.49 (±0.05) inches of mercury at the same time; conversion gives 13.01 psi indicating that 0.09 should be added to give 13.10 psi, the field value. At 10 am on January 20, the Research Center chart read 26.30 inches of mercury or 12.92 psi; adding 0.09 gives 13.01. The field value at the same time was 13.0 psi. A large number of correlations such as these were made with the same result. From January 20 through March 11, the "corrected" Research Center chart values were used for the hourly barometric readings shown in table 2. It should be pointed out that, in general, the 10 am readings shown in table 2 were visually read from the outside through the window of the meter house.

Without going into detail, a large number of pressure-temperature correlations were made manually from inside the meter building as well

as from examination of data during the midnight to early morning hours. In general, a temperature decrease caused a "high" electronic pressure readout and vice-versa. For example, just opening the door of the meter house caused a temperature decrease which was quickly picked up in the electronic counter. Although not always true, the general observation was that a change in temperature of 1 F° caused a pressure readout change of 0.08 psi. These are the "del" values recorded in table 2.

Electronic and deadweight measurements are plotted together in figure 3. As shown, there is a gap in the transducer data from December 22-20; also, there is a gap from December 29-January 5. According to a daily log record which was kept, these shutdowns were due to such reasons as: generator failing to run consistently on Cliffside gas, probably because of freezing-up due to entrained water vapor; generator itself breaking down; fuses and switches in the electronics breaking down; etc. The gap from January 13-18 was due primarily to getting the electronics, generator, blowers, and other equipment checked-out in preparation for following, in detail, the pressure at Bush A-5 as Bush A-9 was scheduled for opening on January 20.

From January 18-27, the electronics were watched closely; this was especially so from about 9 am to 2 pm on January 20, since Bush A-9 was opened to production at 10:55 am. Table 3 summarizes manually controlled and monitored data taken from 10 am to 2:20 pm on January 20. These data were followed very closely to ascertain if there was any "immediate reaction" at Bush A-5 due to opening-up Bush A-9.

as from examination of data during the midnight to early morning hours. In general, a temperature decrease caused a "high" electronic pressure readout and vice-versa. For example, just opening the door of the meter house caused a temperature decrease which was quickly picked up to the electronic counter. Although not always true, the general observation was that a change in temperature of 1 F caused a pressure readout change of 0.08 psi. These are the "dsi" values recorded in table 2.

Electronic and deadweight measurements are plotted together in figure 3. As shown, there is a gap in the transducer data from December 22-26; also, there is a gap from December 29-January 5. According to a daily log record which was kept, these shutdowns were due to such reasons as: generator failing to run consistently on Hillside gas, probably because of freezing-up due to entrained water vapor; generator itself breaking down; fuses and switches in the electronics breaking down; etc. The gap from January 13-18 was due primarily to getting the electronics, generator, blowers, and other equipment checked-out in preparation for following, in detail, the pressure at Bush A-5 as Bush A-9 was scheduled for opening on January 20.

From January 18-27, the electronics were watched closely; this was especially so from about 9 am to 2 pm on January 20, since Bush A-9 was opened to production at 10:55 am. Table 3 summarizes manually controlled and monitored data taken from 10 am to 1:30 pm on January 20. These data were followed very closely to ascertain if there was any "immediate reaction" at Bush A-5 due to opening-up Bush A-9.

Figure 4 shows 5-minute average pressures recorded in table 3. As shown, the pressure had been cycling downward to about 11:20 am; from then until about 12:30 pm it continued cycling downward but not as fast; from then until about 2:20 pm it was cycling steadily around, more-or-less, the same pressure level of the previous day. The only comment, for these data, is that no definite "break" appears to have occurred in the pressure curve; however, its rate of decrease definitely was slowed down during this 4-hour period.

It should be pointed out that one week prior to opening-up Bush A-9, the injection rate into Bivins A-3, the nearby injection well, was suddenly increased from about 8.1 to 8.4-8.5 Mmscf per day, as shown in figure 3. This consistent increase in the injection rate in this particular well would tend to mask a reaction to production from Bush A-9; in fact, prior to January 20, the generally increasing pressure level, as reflected by the deadweight pressures, definitely was slowed down on January 20, as reflected by the transducer values. Also, it should be pointed out that the deadweight value shown on January 20 was taken at 9 am prior to opening Bush A-9.

Figure 4 also shows a plot of hourly average pressures from January 20-25 as recorded in table 2, when the temperature level was constant as explained on pages 14-15. From January 20-22, the transducer pressure was still cycling around a more-or-less common value; between January 22-23 the cycling continued but at a lower pressure level; between January 23-24, however, the cycling was very definitely below the others. From then on the pressure definitely began to cycle

upward again. Tentatively, it appears that a probable "reaction" occurred during the evening of January 23.

The gap in transducer measurements from January 27-February 17 was due to a complete breakdown of the generator; a substitute was brought in from the Exell plant. From February 17-March 11, at which time the transducer measurements were shut-down, represents the longest steady operating period of the electronic module. During this period, both the transducer and deadweight measurements indicate a negative slope in the pressure as shown in figure 3. The slopes of such pressure-time curves, especially from an overall or average reservoir point of view, need to be examined for qualitative correlations as regards the injection - production statistics. The volumetric material or energy balance relationship used for this is presented below.

VOLUMETRIC MATERIAL BALANCE-PRESSURE MAINTENANCE CORRELATION

A reasonable estimate of the relationship between the injected to produced gas ratio and reservoir pressure maintenance level can be made by way of the simple gas law if it is assumed, as a starting point, that there are no permanent barriers to flow, that the reservoir essentially is all gas, and that the reservoir temperature remains sensibly constant. Since the reservoir volume, V, remains constant at a given pressure, P, the product of PV, which is a work or energy term, remains constant or

$$nZ = \frac{PV}{RT} = \text{a constant}, \qquad (1)$$

where the criteria for pressure maintenance is constancy of the product of the number of moles, n, and the Z-factor.

Application of (1) to the injected (i) and produced (p) gas gives, at reservoir conditions:

$$\frac{w_i}{(MW)_i} \times Z_i = \frac{w_p}{(MW)_p} \times Z_p \,, \tag{2}$$

where the w's refer to weights in pounds and the MW's refer to average molecular weights.

For in-place or produced Cliffside gas at 693 psia and 92° F, the average molecular weight is 21.095, Z is 0.9348, and the density, ρ, is 2.645 pounds per cubic foot, as indicated in the section on Absolute Pressure to a Common Datum.

From the work of Miller and Stroud (4), the compressibility factor for the injected conservation 70-30 percent helium-nitrogen mixture was calculated to be 1.0273 at reservoir conditions; these authors tabulated smoothed experimental data into a virial form of equation for computing helium-nitrogen mixture compressibility factors, Z_{mix}, valid for pressures up to 3,400 psia covering a temperature range from 40° to 100° F in 5° increments. The form of this virial equation is

$$Z_{mix} = 1 + B_{mix} P + C_{mix} P^2 + D_{mix} P^3 \,, \tag{3}$$

and the values of B_{mix}, C_{mix}, and D_{mix} can be easily evaluated from data these authors present. The assumed average molecular weight for the 70-30 percent injected helium-nitrogen mixture is 11.2; the computed density is 1.278 pounds per cubic foot, based on the relation

$$\rho = \frac{P\bar{M}}{ZRT} = \frac{693 \times 11.2}{1.0273 \times 10.71 \times 552} . \tag{4}$$

Substituting for the Z-factors and average molecular weights in (2) gives

$$\frac{w_i}{11.2} \times 1.0273 = \frac{0.9348}{21.095} \times w_p , \tag{5}$$

or

$$w_i = 0.4831 \times w_p . \tag{6}$$

Since weight is density, ρ, times volume, V,

$$V_i \rho_i = 0.4831 V_p \rho_p , \tag{7}$$

or

$$V_i (1.278) = 0.4831 (V_p) (2.645) , \tag{8}$$

or

$$V_i/V_p = 0.99976 \doteq 1 , \tag{9}$$

at reservoir conditions.

Equation (9) represents a rigorous derivation of a fact that sometimes is taken for granted; that is, in order to maintain reservoir pressure for a fixed total void space, assuming no internal influx of any type of fluid, the reservoir volume of injected fluid equals the reservoir volume of all withdrawals; further, it tends to substantiate the correctness of the values used for compressibilities, average molecular weights, and densities at reservoir conditions. It should be pointed out that the only rigorous way to determine the correct molecular weight is to experimentally determine it; the 21.095 field average used is probably in error and, since the gas density is computed using this, the gas

gradients shown in table 1 are in error. However, these are in error by a constant amount and do not change the pressure gradients discussed in the following section. Moreover, if a molecular weight of 20.51, the overall field average determined over a longer time period and covering more wells, is used in equation (5), it leads to the same result shown in equation (9), when the corresponding density (2.572) is used; further, from a rigorous point of view this average molecular weight also is not precisely correct.

The general equation which incorporates the Z-factor is

$$V = Z\,V_{ideal}\ , \tag{10}$$

where

V = the true volume at the given conditions of temperature and pressure,

V_{ideal} = the volume at the given temperature and pressure, if the gas were ideal, and

Z = the compressibility factor at the given temperature and pressure.

The volume in the reservoir occupied by the injected gas, V_{irc}, is

$$V_{irc} = V_{iscf} \times \frac{14.65}{693} \times \frac{552}{520} \times Z_{irc}\ , \tag{11}$$

where V_{iscf} is standard cubic feet of gas injected at 60° F and 14.65 psia, and Z_{irc} is the compressibility factor of the injected gas at reservoir conditions. The corresponding equation for the produced gas is

$$V_{prc} = V_{pscf} \times \frac{14.65}{693} \times \frac{552}{520} \times Z_{prc}\ . \tag{12}$$

Dividing (11) by (12) gives, by way of (9),

$$\frac{V_{iscf} \times Z_{irc}}{V_{pscf} \times Z_{prc}} = 1 \ , \tag{13}$$

or

$$\frac{V_{iscf}}{V_{pscf}} = 1 \times \frac{Z_{prc}}{Z_{irc}} \ , \tag{14}$$

or

$$\frac{V_{iscf}}{V_{pscf}} = 1 \times \frac{0.9348}{1.0273} = 0.90 \ . \tag{15}$$

The preceding reasonable estimate indicates that, in order to maintain the reservoir pressure level at a nominal 700 psia, the injected to produced gas volume ratio at standard engineering conditions should be at least 0.90. Another way of stating this relation is that

$$\frac{V_{iscf}}{V_{pscf}} - 0.90 = 0 \ , \tag{16}$$

or whenever relation (16) is greater than zero means an "excess" of injected energy or an increasing pressure level.

Table 4 summarizes daily injection-production statistics for the gas storage reservoir from October 1965 through February 1966 and shows the volume injected to volume produced ratio, V_i/V_p, as well as values of relation (16) which are termed delta, Δ. Table 5 summarizes daily deadweight pressures for Bush A-5, Bush A-4, Fuqua A-2, Bush A-9 (prior to opening), Bivins A-7, and Bush A-2. These are not all of the wells in the present stabilization area (figure 1), but they are, for

the purposes of this report, the ones of most interest because of their locations. Unfortunately, Bush A-2 deadweight pressures were taken weekly until February 16 when daily measurements were started. The average (reservoir) pressures, presented in the last column of table 5, are simply arithmetic averages of all the wells just mentioned except Bush A-2. Figure 3 also shows a plot of average pressures of all these wells from December 1965 through February 1966; right below these pressures are the daily delta values rounded off to 0.1.

DISCUSSION OF PRESSURE MAINTENANCE - VOLUMETRIC MATERIAL BALANCE CORRELATION

On a short-range time basis, the only pressure-time plots of individual well pressures which showed any definite trend were the transducer values from January 20-27 and February 20-28 for Bush A-5 when the slope was negative (figure 3). On a long-range time basis, the deadweight pressure-time plots for individual wells, which are not shown in this report, show a general positive slope from October 1965 through February 1966, except for Bush A-5 where the slope is approximately negative during February. There is no apparent correlation between the daily or monthly individual well deadweight pressure-time and delta-time plots, also not shown in this report; that is, individual wells do not appear to follow any pressure-time behavior pattern as regards injection - production rates. However, deadweight pressures arithmetically averaged for all wells (all wells except Bush A-2) do appear to follow a pattern as regards the corresponding deltas; for example, even though there are some anomalies, when delta definitely

decreases the slope of the average pressure for all wells decreases; also, when delta definitely increases there appears to be a 2-3 day lag for the slope of the pressure to increase (figure 3). This tends to confirm the "probable" reaction of Bush A-5 on the "evening" of January 23.

Table 6 shows average least square, assumed straight line slopes of the pressure-time plots, on a monthly basis, from October 1965 through February 1966; values for individual wells have been rounded-off, as shown, to be consistent with the accuracy of the deadweight tester; average values for "all" wells, in the stabilization area, are shown to an extra decimal place because they represent about five times more data points. Correlation plots of these data are shown in figure 5.

Overall, the most indicative correlation results from a comparison of the average pressure slope of all wells, from October 1965 - February 1966, with the running average delta values shown in table 6 and plotted in figure 5. These particular data follow what one would anticipate except during December-January there is a relatively large decrease in the pressure slope with a relatively smaller increase in delta; however, in this period only four wells are being averaged, one of which (Bush A-5) exhibited a relatively larger decrease in slope than any of the others.

If the assumption is made that the "base" starting pressure is 707.8 (October 1965 average) and 0.89 is the base starting delta (October 1965 average), a strictly qualitative prediction of pressures can be

made; the running average delta from October 1965 - February 1966 was 1.09 at the end of this period and the corresponding average running pressure was 711.7. Delta changed 0.20 dimensionless units and the pressure changed by 3.9 psi or 19.5 psi per delta. Table 6 also shows, in the lower last two columns, the monthly change in the running delta average and the corresponding predicted running average pressure based on the changes in delta. These predicted pressures indicate longer periods of the maintenance of increasing or decreasing pressure slopes instead of a continuous increase in pressure slopes as indicated by the average deadweight pressures and lead to the suspicion that more accurate and reproducible deadweight pressures should be strived for.

From what has already been said, it would appear rather obvious that Bush A-9 is in better communication with Bush A-5 than Bush A-5 is with the nearby injection well, Bivins A-3, in spite of the fact that Bush A-9 is about 200 feet further away from Bush A-5 than the distance between Bush A-5 and Bivins A-3. Also, the injected gas, predominately around Bivins A-3, has a higher viscosity (about 200 micropoises) than the in-place gas (about 150 micropoises) and, consequently, experiences more difficulty in moving through the reservoir.

Figure 5 also shows the average slope of the monthly pressures of the individual wells for the same time period. Some data trends and anomalies are indicated. For example, between October - December 1965, even though delta exhibited a relatively large increase, the pressure slopes of Bush A-4 and Bivins A-7 definitely decreased; at the same

made; the running average delta from October 1965 - February 1966 was 1.09 at the end of this period and the corresponding average running pressure was 711.7. Delta changed 0.20 dimensionless units and the pressure changed by 3.9 psi or 19.5 psi per delta. Table 6 also shows, in the lower last two columns, the monthly change in the running delta average and the corresponding predicted running average pressure based on the changes in delta. These predicted pressures indicate longer periods of the maintenance of increasing or decreasing pressure levels which appear to cycle instead of a continuous increase in pressure as indicated by the average deadweight pressures and lead to the suspicion that more accurate and reproducible deadweight pressures should be strived for.

From what has already been said, it would appear rather obvious that Bush A-9 is in better communication with Bush A-5 than Bush A-5 is with the nearby injection well, Bivins A-3, in spite of the fact that Bush A-9 is about 200 feet further away from Bush A-5 than the distance between Bush A-5 and Bivins A-3. Also, the injected gas, predominately around Bivins A-3, has a higher viscosity (about 200 micropoises) than the in-place gas (about 150 micropoises) and, consequently, experiences more difficulty in moving through the reservoir.

Figure 5 also shows the average slope of the monthly pressures of the individual wells for the same time period. Some data trends and anomalies are indicated. For example, between October - December 1965, even though delta exhibited a relatively large increase, the pressure slopes of Bush A-4 and Bivins A-7 definitely decreased; at the same

time, the pressure slopes of Bush A-5 and Bush A-9 definitely increased. This indicates that the area from Bivins A-3 towards Bush A-5 and Bush A-9 is in better communication than with the area towards Bivins A-7 and Bush A-4. From December 1965 - January 1966, the decreasing pressure slope was "stabilized" at Bivins A-7, indicating the "reaction" of this well to an increasing delta during this period; the pressure slope at Bush A-4, however, continued its rapid decrease. This trend indicates better communication between Bivins A-7 and Bivins A-3 than between Bivins A-3 and Bush A-4, in spite of the fact that Bivins A-7 is about 350 feet further away. From January - February 1966, the pressure slopes of all wells increased except Bush A-5. As indicated above, the rapid decrease in Bush A-5 is overweighted as regards the average pressure for all the wells for that period. The behavior of Fuqua A-2, which is relatively further away from Bivins A-3, has reacted as one might expect; that is, no particular pressure slope increase or decrease until December - January - February when the slope generally increases. This indicated delayed reaction of Fuqua A-2 also could mean that the area from Bivins A-3 towards Fuqua A-2 is tighter than either of the areas towards Bivins A-7 or Bush A-4.

CONCLUSIONS AND RECOMMENDATIONS

Based on the previous discussions the following are concluded:

1. The electronic method of measuring wellhead pressures, good to about 0.1 psi, is especially indicative of short-range pressure-time correlations; also, these measurements could be made more accurate and precise;

2. The deadweight tester method is useful for long-range pressure-time trends (two-three months) but needs to be made more accurate and precise;

3. Bush A-9 definitely is in better communication with Bush A-5 than Bush A-5 is with the nearest gas injection well, Bivins A-3;

4. The reservoir as a whole, based on the change of the pressure slope with time and the volumetric material balance correlation, appears to be in relatively good communication, considering its tight nature;

5. Individual wells reported in the stabilization area do not appear to have permanent flow barriers;

6. Bush A-5 probably reacted to production from Bush A-9 in about 3-1/2 days;

7. The volumetric pressure maintenance - material balance correlation can be used on a routine basis to establish preselected pressure maintenance levels for preselected injection - production rates;

8. The area between Bush A-5 and Bush A-9 appears to be in better communication than that between Bush A-5 and Bivins A-3; the area between Bivins A-7 and Bivins A-3 appears to be in better communication than that between Bivins A-3 and Bush A-4; the area around Fuqua A-2 may be the tightest of those reported.

Based primarily on experience gained, the following recommendations are made:

1. Future work of this nature can be done with less difficulty and in a semi-routine manner if public service power and better weather protection are provided. Also, field personnel could be more familiar-

ized with the electronic equipment, so that only major breakdowns would require special handling; also, the ordinary window in the meter house could be replaced with a "thermal pane" window, among other things for better temperature control.

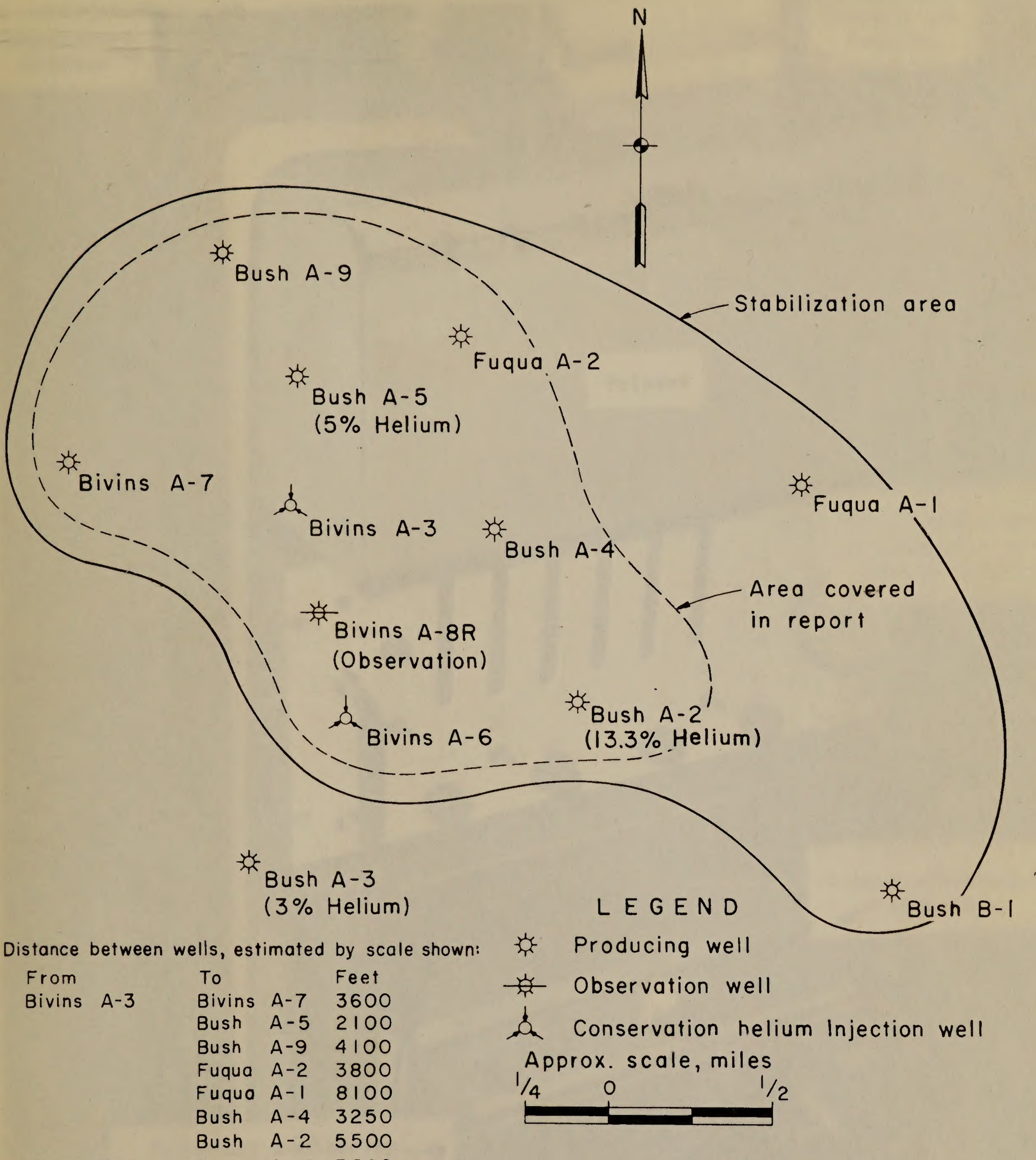
2. The electronic measurements could be made more accurate and reproducible by eliminating the voltage-to-frequency converter and the electronic counter and replacing them by a suitable digital voltmeter (an extra cost of about $3,000 for a new one). With this instrument, it is estimated that the overall accuracy would approach 0.065 psig and the overall reproducibility 0.01 psi, assuming better temperature control of the readout equipment. The problem of readout temperature control remains the main problem, whether these or similar measurements are made at the wellhead or at bottom-hole conditions. From the point of view of accuracy, the surface readout cannot be better than the basic standard, which in this case is the Ruska deadweight gage.

3. Since it does not appear that the field will be electrified in the near future, electronic measurements on key closed-in wells, such as Bush A-5, should continue, even on an intermittent basis. The power generator should be run exclusively on gasoline between the hours of about 4 pm to 8 am the next day since the most accurate measurements usually occur from about midnight to 5 am. Such a schedule would require 25 gallons of gasoline and would cost about $4.25 per recommended operating period.

4. If possible, individual deadweight pistons should be installed on a semi-permanent basis inside each meter house. This would be so

that the temperature of the oil inside the deadweight tester would be stabilized to that inside each meter house.

5. Consideration should be given, even from a qualitative point of view, to locally setting up a mathematical model and employing a digital computer to predict and compare average reservoir pressures, gas flow rates, and cumulative gas production as outlined, for example, in recent publications (such as How to Evaluate Well Locations in a Gas-Storage Reservoir, by R. C. Hessing, Oil and Gas Journal, v. 64, March 7, 1966, pp. 105-108, as well as others).



Distance between wells, estimated by scale shown:

From	To	Feet
Bivins A-3	Bivins A-7	3600
	Bush A-5	2100
	Bush A-9	4100
	Fuqua A-2	3800
	Fuqua A-1	8100
	Bush A-4	3250
	Bush A-2	5500
Bivins A-6	Bush A-4	3800
	Fuqua A-1	8100
	Bush A-2	3700
	Bush B-1	9100
Bush A-5	Bivins A-7	3850
	Bush A-9	2300
	Fuqua A-2	2650

FIGURE 1.- Stabilization Area Northern Section Cliffside Field

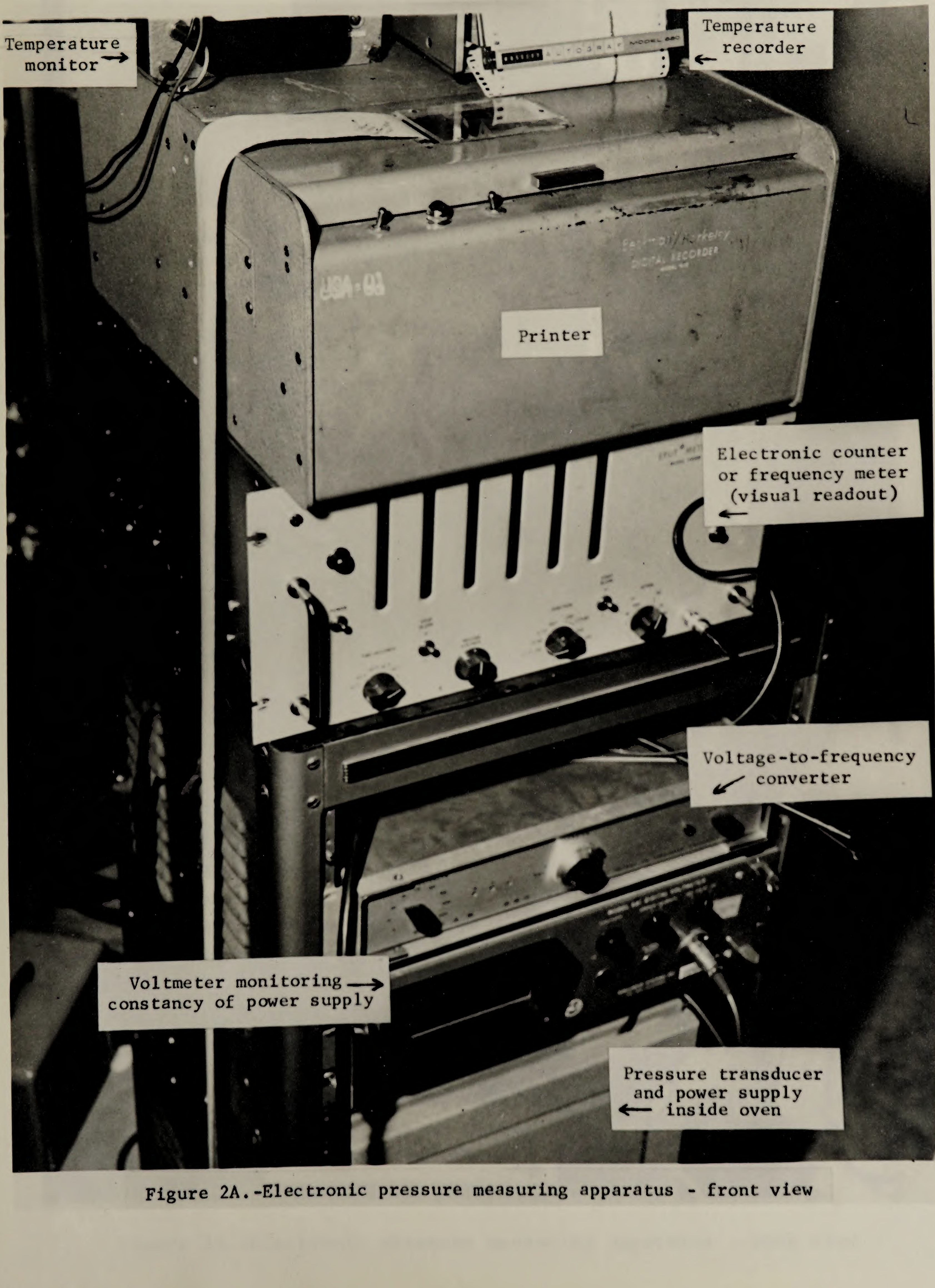


Figure 2A.-Electronic pressure measuring apparatus - front view

Figure 2B.-Electronic pressure measuring apparatus - back view

Figure 2C.-Electronic pressure measuring apparatus - outside view

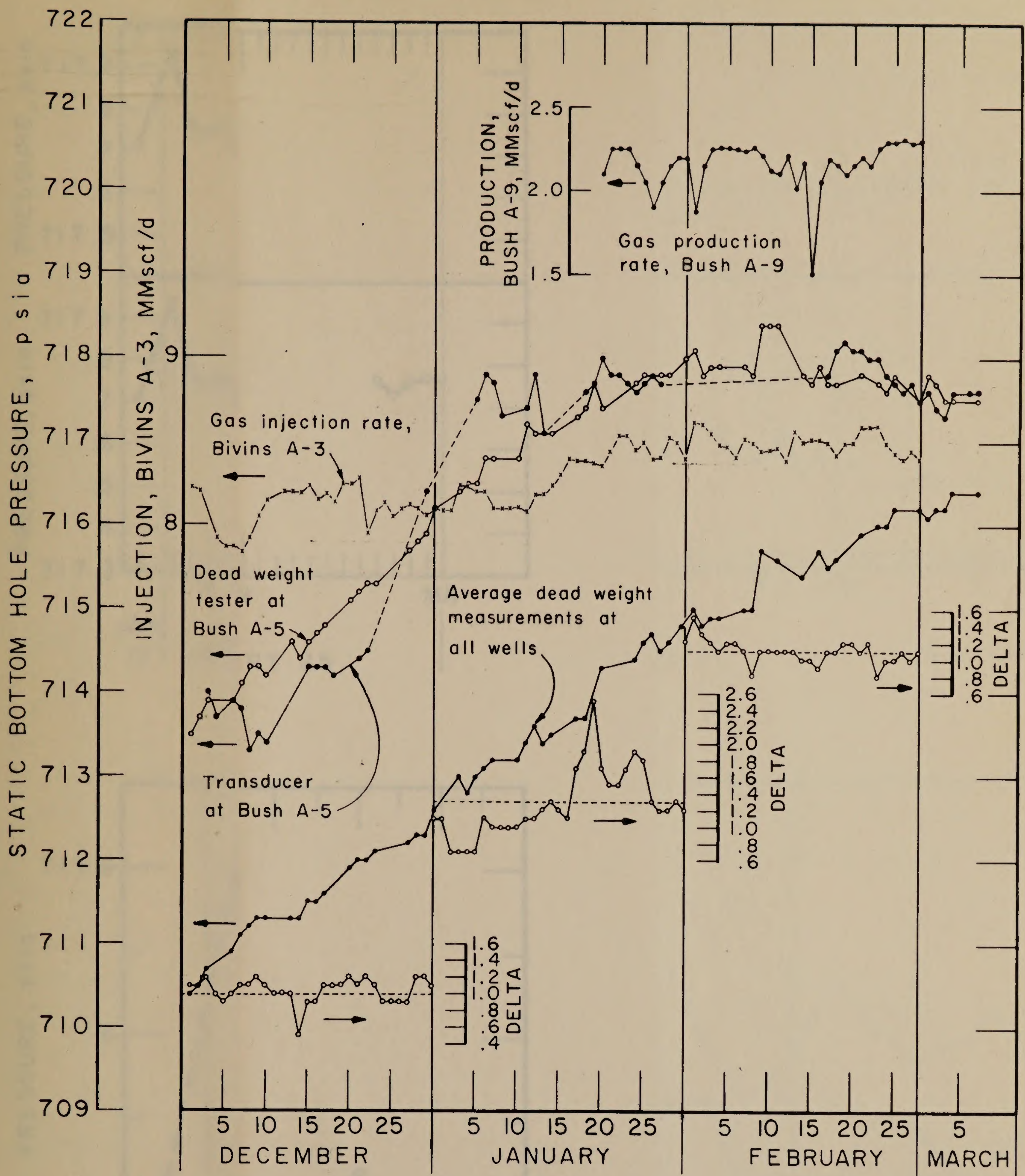


FIGURE 3.- Summary Pressure-Production Data, December 1965 - January 1966, Cliffside Reservoir

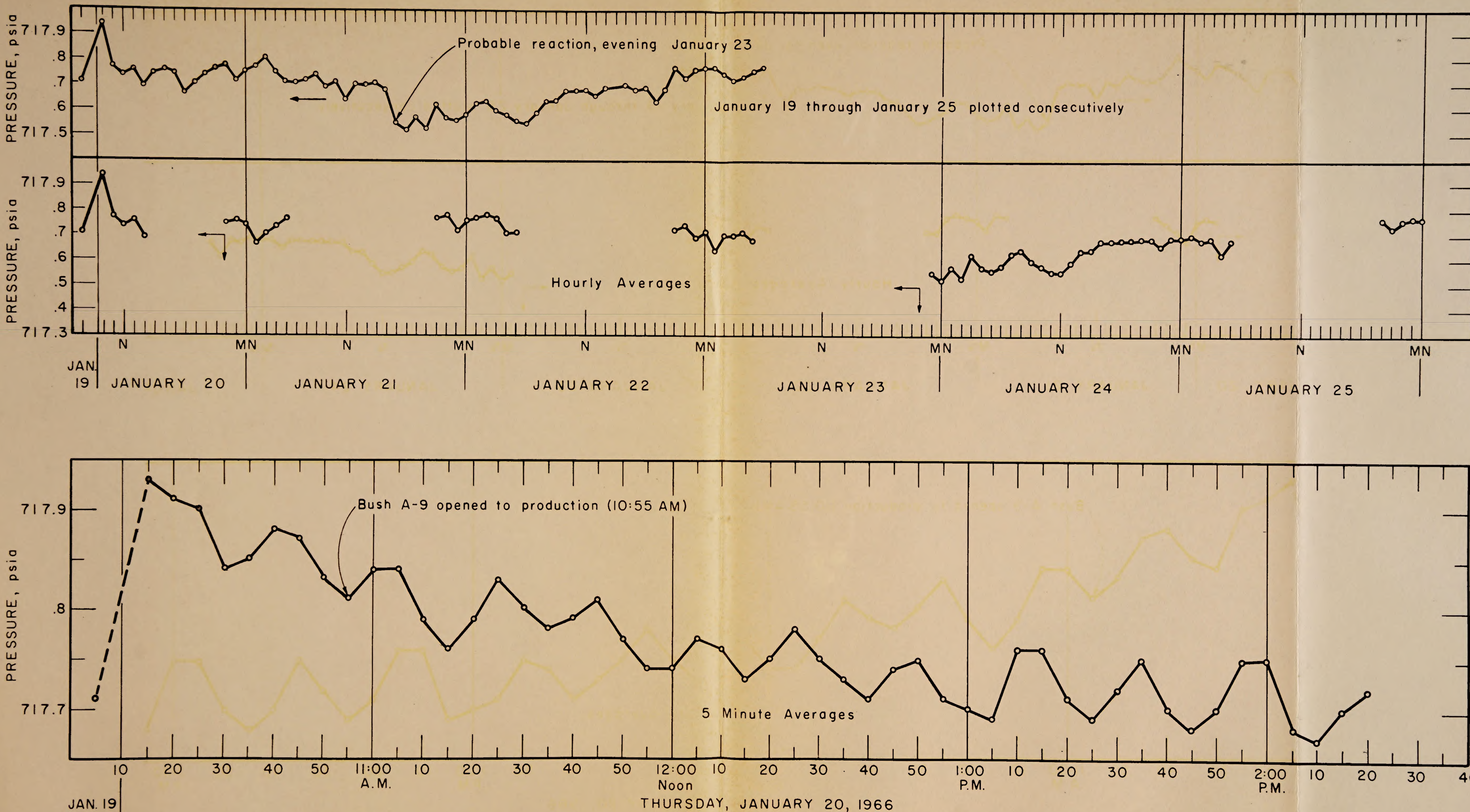


FIGURE 4. - Electronic Pressure Readout, Bush A-5

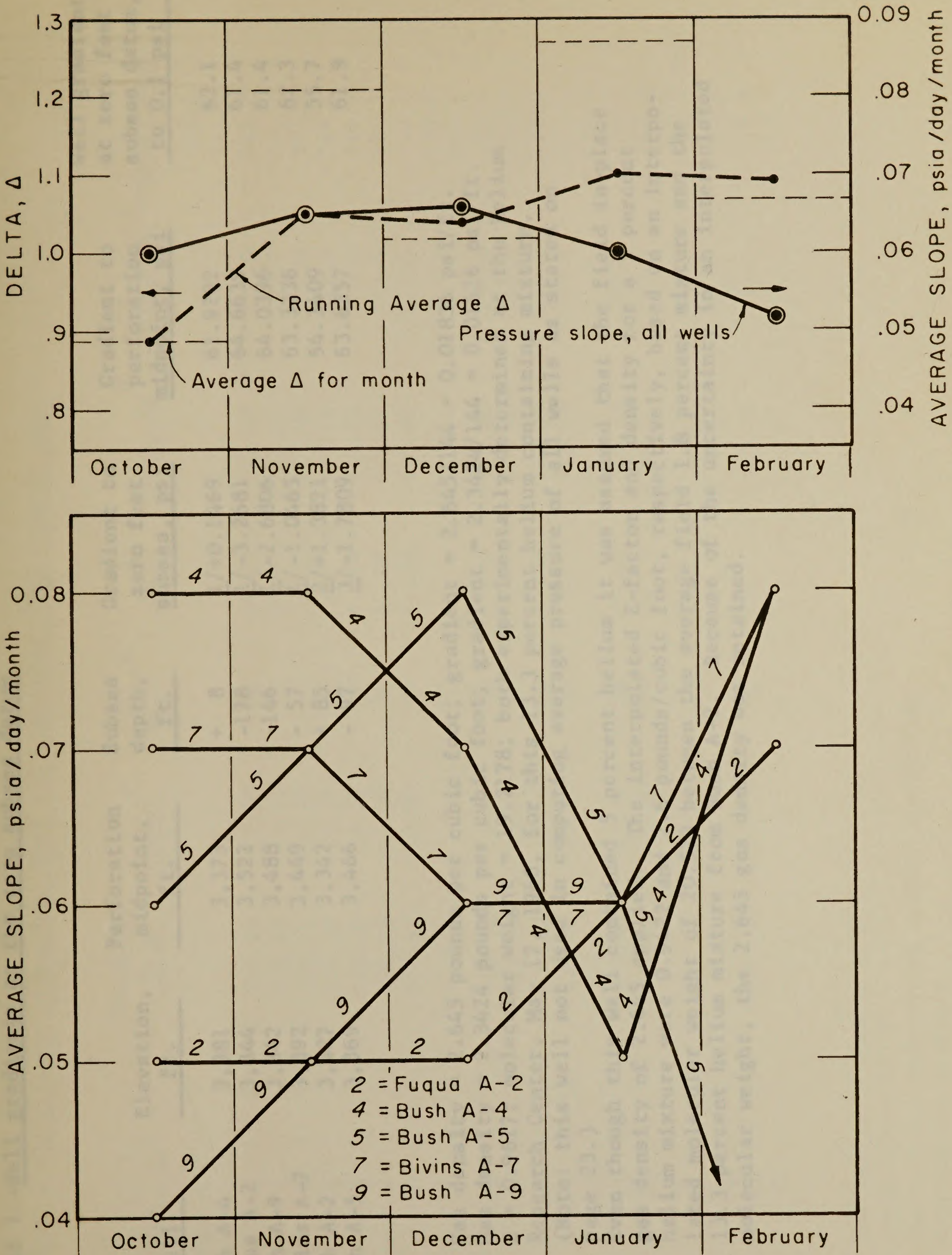


FIGURE 5.- Slope of Pressure, Volumetric Material Balance Correlation.

TABLE 1.-Well gradients at the zero subsea datum

Well	Elevation, ft.	Perforation midpoint, ft.	Subsea depth, ft.	Gradient to zero feet subsea, psi	Gradient to perforation midpoint, psi	Well gradient at zero feet subsea datum, to 0.1 psi
Bush A-4	3,381	3,373	+ 8	1/+0.1469	61.9282	62.1
Fuqua A-2	3,344	3,522	-178	1/-3.2681	64.6639	61.4
Bush A-9	3,342	3,488	-146	1/-2.6806	64.0396	61.4
Bivins A-7	3,392	3,449	- 57	1/-1.0465	63.3236	62.3
Bush A-2	3,427	3,342	+ 85	2/+1.3821	54.3409	55.7
Bush A-5	3,369	3,466	- 97	3/-1.7809	63.6357	61.9

1/ Gas density = 2.645 pounds per cubic foot; gradient = 2.645/144 = 0.01836 psi/ft.

2/ Gas density = 2.3424 pounds per cubic foot; gradient = 2.3424/144 = 0.01626 psi/ft. Z = 0.9617; molecular weight = 19.2178; both experimentally determined at the Helium Research Center, May 17, 1966, for this 13.3 percent helium containing mixture. (Note: this well not used in computing average pressure of all wells as stated on page 23.)

3/ Even though this well contained 5 percent helium it was assumed that the field in-place gas density of 2.645 applied. The interpolated Z-factor and density for a 5 percent helium mixture were 0.9422 and 2.6 pounds/cubic foot, respectively, based on an interpolated molecular weight of 20.573 between the average field 1.8 percent mixture and the 13.3 percent helium mixture from Bush A-2. Because of the uncertainty in an interpolated molecular weight, the 2.645 gas density was retained.

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966

Date	Wellhead, Psig	Baro[a]	T, °F[b]	Del[c]	Psia, BH[d]	Psia, BH	Psia, BHDW[e]
December 1							713.5
2							713.7
3	638.48	13.20	90	+0.40	713.98	714.0	713.9
4	638.32	13.11	90	+ .40	713.73	713.7	
6	638.78	13.20	85	0	713.88	713.9	713.9
7	638.78	13.10	85	0	713.78	713.8	714.1
8	638.09	13.10	87	+ .16	713.25	713.3	714.3
9	638.49	13.00	86	+ .08	713.47	713.5	714.3
10	638.42	13.00	86	+ .08	713.40	713.4	714.2
13							714.6
							714.4
15	639.32	13.00	86	+ .08	714.30	714.3	714.6
16	639.30	13.10	85	0	714.30	714.3	714.7
17	639.22	13.10	86	+ .08	714.30	714.3	714.8
18	639.24	13.05	85	0	714.19	714.2	
20							715.1
21	639.40	13.00	86	+ .08	714.38	714.4	715.2
22	639.62	13.00	85	0	714.52	714.5	715.3
23							715.3
27							715.7
28							715.8
29	641.42	13.10	85	0	716.42	716.4	715.9
30							716.2

[a] Barometric pressure, psi
[b] Temperature in °F
[c] Electronics temperature readout correction
[d] Bottom-hole pressure
[e] Bottom-hole pressure deadweight tester

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date		Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
January 3								716.4
4								716.5
5		642.35	13.10	86.5	+0.12	717.47	717.5	716.5
6		642.68	13.20	85	0	717.78	717.8	716.8
7		642.57	13.20	85	0	717.67	717.7	716.8
8		642.28	13.12	85	0	717.30	717.3	
10								716.8
11		642.47	13.00	85	0	717.37	717.4	717.2
12		642.25	13.10	90	+ .40	717.75	717.8	717.1
13	12 MN	642.20	13.06	86	+ .08	717.24	717.2	
	10 am	642.14	13.10	86	+ .08	717.14	717.1	717.1
14								717.1
17								717.3
18	2 pm	643.04	13.00	81	- .32	717.62	717.6	717.4
19	2 pm	642.97	12.92	84	- .08	717.71	717.7	717.7
20	10 am (1)	643.03	13.01	85	0	717.94	717.9	717.4
	11 am (1)	642.86	13.01	85	0	717.77	717.8	
	12 N (1)	642.83	13.01	85	0	717.74	717.7	
	1 pm (1)	642.86	13.00	85	0	717.76	717.8	
	2 pm (1)	642.80	12.99	85	0	717.69	717.7	
	Avg	642.88		85	0	717.78	717.8	
	10 pm	642.86	12.99	85	0	717.75	717.8	
	11 pm	642.87	12.99	85	0	717.76	717.8	

(1) Actually correspond to 10:15, 11:15, etc.

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date		Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
January 21	12 MN	642.86	12.99	85	0	717.75	717.8	
	1 am	642.79	12.98	85	0	717.67	717.7	
	2 am	642.83	12.98	85	0	717.71	717.7	
	3 am	642.86	12.98	85	0	717.74	717.7	
	4 am	642.88	12.99	85	0	717.77	717.8	
	Avg	642.85		85	0	717.76	717.8	717.4
	9 pm	642.83	13.04	85	0	717.77	717.8	
	10 pm	642.83	13.05	85	0	717.78	717.8	
	11 pm	642.77	13.05	85	0	717.72	717.7	
22	12 MN	642.81	13.05	85	0	717.76	717.8	
	1 am	642.82	13.05	85	0	717.77	717.8	
	2 am	642.86	13.05	85	0	717.81	717.8	
	3 am	642.80	13.05	85	0	717.75	717.8	
	4 am	642.77	13.04	85	0	717.71	717.7	
	5 am	642.77	13.04	85	0	717.71	717.7	
	Avg	642.81		85	0	717.75	717.8	
	9 pm	642.82	13.00	85	0	717.72	717.7	
	10 pm	642.84	13.00	85	0	717.74	717.7	
	11 pm	642.80	12.99	85	0	717.69	717.7	
23	12 MN	642.82	12.99	85	0	717.71	717.7	
	1 am	642.76	12.98	85	0	717.64	717.6	
	2 am	642.82	12.98	85	0	717.70	717.7	
	3 am	642.82	12.98	85	0	717.70	717.7	
	4 am	642.84	12.97	85	0	717.71	717.7	
	5 am	642.82	12.96	85	0	717.68	717.7	
	Avg	642.82		85	0	717.70	717.7	

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date		Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
January 23	11 pm	642.76	12.89	85	0	717.55	717.6	
24	12 MN	642.73	12.89	85	0	717.52	717.5	
	1 am	642.78	12.89	85	0	717.57	717.6	
	2 am	642.74	12.89	85	0	717.53	717.5	
	3 am	642.83	12.89	85	0	717.62	717.6	
	4 am	642.78	12.89	85	0	717.57	717.6	
	5 am	642.77	12.89	85	0	717.56	717.6	
	6 am	642.78	12.90	85	0	717.58	717.6	
	Avg	642.77		85	0	717.56	717.6	
	7 am	642.82	12.91	85	0	717.63	717.6	
	8 am	642.82	12.92	85	0	717.64	717.6	
	9 am	642.76	12.94	85	0	717.60	717.6	
	10 am	642.73	12.95	85	0	717.58	717.6	717.7
	11 am	642.71	12.95	85	0	717.56	717.6	
	12 N	642.70	12.95	85	0	717.55	717.6	
	1 pm	642.69	13.00	85	0	717.59	717.6	
	2 pm	642.74	13.00	85	0	717.64	717.6	
	3 pm	642.72	13.00	85	0	717.64	717.6	
	4 pm	642.78	13.00	85	0	717.68	717.7	
	5 pm	642.78	13.00	85	0	717.68	717.7	
	Avg	642.75		85	0	717.62	717.6	
	9 pm	642.78	13.00	85	0	717.68	717.7	
	10 pm	642.76	13.00	85	0	717.66	717.7	
	11 pm	642.79	13.00	85	0	717.69	717.7	
25	12 MN	642.79	13.00	85	0	717.69	717.7	
	1 am	642.80	13.00	85	0	717.70	717.7	

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date		Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
January 25	2 am	642.78	13.00	85	0	717.68	717.7	
	3 am	642.79	13.00	85	0	717.69	717.7	
	4 am	642.73	13.00	85	0	717.63	717.6	
	5 am	642.78	13.00	85	0	717.68	717.7	
	Avg	642.78		85	0	717.68	717.7	717.8
	8 pm	642.82	13.05	85	0	717.77	717.8	
	9 pm	642.78	13.05	85	0	717.73	717.7	
	10 pm	642.80	13.06	85	0	717.76	717.8	
	11 pm	642.81	13.06	85	0	717.77	717.8	
26	12 MN	642.80	13.07	85	0	717.77	717.8	
	1 am	642.79	13.06	85	0	717.75	717.8	
	2 am	642.75	13.07	85	0	717.72	717.7	
	3 am	642.76	13.07	85	0	717.73	717.7	
	4 am	642.79	13.07	85	0	717.76	717.8	
	5 am	642.80	13.07	85	0	717.77	717.8	
	Avg	642.79		85	0	717.75	717.8	717.8
27	12 MN	642.74	13.05	85	0	717.69	717.7	
	1 am	642.74	13.05	85	0	717.69	717.7	
	2 am	642.73	13.04	85	0	717.67	717.7	
	3 am	642.77	13.03	85	0	717.70	717.7	
	4 am	642.72	13.02	85	0	717.64	717.6	
	Avg	642.74		85	0	717.68	717.7	717.8

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date		Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
February 17	10 am	642.80	12.97	84	-0.08	717.75	717.8	717.7
18	8 am	643.55	12.91	84	- .08	718.28	718.3	
	9 am	643.42	12.91	84	- .08	718.15	718.2	
	Avg	643.49		84	- .08	718.06	718.1	717.7
19	2 am	642.42	13.00	84	- .08	718.24	718.2	
	3 am	643.33	13.01	84	- .08	718.16	718.2	
	4 am	643.38	13.01	84	- .08	718.21	718.2	
	5 am	643.26	13.01	84	- .08	718.09	718.1	
	6 am	643.39	13.03	84	- .08	718.24	718.2	
	Avg	643.36		84	- .08	718.19	718.2	
20	1 am	643.24	13.06	84	- .08	718.12	718.1	
	2 am	643.19	13.06	84	- .08	718.07	718.1	
	3 am	643.18	13.07	84	- .08	718.07	718.1	
	4 am	643.14	13.06	84	- .08	718.02	718.0	
	5 am	643.16	13.06	84	- .08	718.04	718.0	
	6 am	643.16	13.06	84	- .08	718.04	718.0	
	Avg	643.18		84	- .08	718.06	718.1	
21	3 am	643.08	13.12	84	- .08	718.02	718.0	
	4 am	642.97	13.12	84	- .08	717.91	717.9	
	5 am	643.02	13.13	84	- .08	717.97	718.0	
	6 am	643.10	13.13	84	- .08	718.05	718.1	
	Avg	643.04		84	- .08	717.99	718.0	

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date		Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
February 21	10 am	643.09	13.17	84	-0.08	718.08	718.1	717.8
22	1 am	643.04	13.19	84	- .08	718.05	718.1	
	2 am	643.03	13.19	84	- .08	718.04	718.0	
	3 am	643.10	13.18	84	- .08	718.10	718.1	
	4 am	642.99	13.17	84	- .08	717.98	718.0	
	5 am	643.03	13.17	84	- .08	718.02	718.0	
	6 am	643.05	13.17	84	- .08	718.04	718.0	
	Avg	643.05		84	- .08	718.04	718.0	
23	1 am	643.03	13.15	84	- .08	718.00	718.0	
	2 am	643.00	13.15	84	- .08	717.97	718.0	
	3 am	643.01	13.14	84	- .08	717.97	718.0	
	4 am	643.02	13.14	84	- .08	717.98	718.0	
	5 am	643.02	13.13	84	- .08	717.97	718.0	
	6 am	643.03	13.13	84	- .08	717.98	718.0	
	Avg	643.02		84	- .08	717.98	718.0	
	10 am	642.90	13.14	86	+ .08	718.02	718.0	717.7
24	3 am	642.91	13.08	84	- .08	717.81	717.8	
	4 am	642.95	13.07	84	- .08	717.84	717.8	
	5 am	642.89	13.06	84	- .08	717.77	717.8	
	6 am	642.94	13.06	84	- .08	717.82	717.8	
	7 am	642.96	13.06	84	- .08	717.84	717.8	
	Avg	642.93		84	- .08	717.82	717.8	

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date		Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
February 24	10 am	642.77	13.06	86	+0.08	717.81	717.8	717.6
25	1 am	642.80	13.01	84	- .08	717.63	717.6	
	2 am	642.84	13.01	84	- .08	717.67	717.7	
	3 am	642.89	13.00	84	- .08	717.71	717.7	
	4 am	642.89	13.00	84	- .08	717.71	717.7	
	5 am	642.83	12.99	84	- .08	717.64	717.6	
	Avg	642.85		84	- .08	717.67	717.7	717.8
26	1 am	642.89	12.91	84	- .08	717.62	717.6	
	2 am	642.87	12.90	84	- .08	717.59	717.6	
	3 am	642.83	12.90	84	- .08	717.55	717.6	
	4 am	642.85	12.89	84	- .08	717.56	717.6	
	5 am	642.85	12.89	84	- .08	717.56	717.6	
	6 am	642.91	12.88	84	- .08	717.61	717.6	
	Avg	642.87		84	- .08	717.58	717.6	
27	1 am	642.87	12.85	84	- .08	717.54	717.5	
	2 am	642.83	12.84	84	- .08	717.49	717.5	
	3 am	642.79	12.84	84	- .08	717.45	717.5	
	4 am	642.81	13.32	84	- .08	717.95	718.0	
	5 am	642.85	13.32	84	- .08	717.99	718.0	
	Avg	642.83		84	- .08	717.68	717.7	
28	1 am	642.75	12.94	84	- .08	717.51	717.5	
	2 am	642.75	12.94	84	- .08	717.51	717.5	
	3 am	642.74	12.94	84	- .08	717.50	717.5	
	4 am	642.75	12.95	84	- .08	717.52	717.5	
	5 am	642.71	12.95	84	- .08	717.48	717.5	
	Avg	642.74		84	- .08	717.50	717.5	717.5

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date			Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
March	1	10 am	642.71	12.94	85	0	717.55	717.6	717.8
	2	1 am	642.71	12.78	84	- .08	717.31	717.3	
		2 am	642.71	12.77	84	- .08	717.30	717.3	
		3 am	642.72	12.77	84	- .08	717.31	717.3	
		4 am	642.71	12.76	84	- .08	717.29	717.3	
		5 am	642.68	12.76	84	- .08	717.26	717.3	
		Avg	642.71				717.29	717.3	
		10 am	642.62	12.75	86	+ .08	717.35	717.4	717.7
	3	1 am	642.66	12.78	84	- .08	717.26	717.3	
		2 am	642.66	12.78	84	- .08	717.26	717.3	
		3 am	642.66	12.78	84	- .08	717.26	717.3	
		4 am	642.69	12.78	84	- .08	717.29	717.3	
		5 am	642.64	12.78	84	- .08	717.24	717.2	
		Avg	642.66		84	- .08	717.26	717.3	717.5
	4	3 am	642.73	12.95	84	- .08	717.50	717.5	
		4 am	642.71	12.96	84	- .08	717.49	717.5	
		5 am	642.74	12.97	84	- .08	717.53	717.5	
		6 am	642.71	12.99	84	- .08	717.52	717.5	
		7 am	642.69	13.00	84	- .08	717.51	717.5	
		Avg	642.72		84	- .08	717.51	717.5	
		10 am	642.65	13.04	85	0	717.59	717.6	717.5
	5	1 am	642.70	13.09	84	- .08	717.61	717.6	
		2 am	642.68	13.09	84	- .08	717.59	717.6	
		3 am	642.66	13.09	84	- .08	717.59	717.6	
		4 am	642.72	13.10	84	- .08	717.64	717.6	
		5 am	642.74	13.11	84	- .08	717.67	717.7	

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date			Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
March	6	Avg	642.70		84	-0.08	717.62	717.6	
		1 am	642.74	13.10	84	- .08	717.66	717.7	
		2 am	642.77	13.10	84	- .08	717.69	717.7	
		3 am	642.68	13.09	84	- .08	717.59	717.6	
		4 am	642.71	13.08	84	- .08	717.61	717.6	
		5 am	642.73	13.08	84	- .08	717.63	717.6	
	7	Avg	642.73		84	- .08	717.64	717.6	
		1 am	642.66	13.06	84	- .08	717.54	717.5	
		2 am	642.70	13.06	84	- .08	717.58	717.6	
		3 am	642.66	13.05	84	- .08	717.53	717.5	
		4 am	642.65	13.05	84	- .08	717.52	717.5	
		Avg	642.67		84	- .08	717.54	717.5	
		10 am	642.64	13.05	85	0	717.59	717.6	717.5
	8	3 am	642.55	13.00	84	- .08	717.37	717.4	
		4 am	642.59	13.00	84	- .08	717.41	717.4	
		5 am	642.56	13.00	84	- .08	717.38	717.4	
		Avg	642.56		84	- .08	717.39	717.4	
		10 am	642.41	13.04	85	0	717.35	717.4	717.6
	9	12MN	642.51	13.04	84	- .08	717.37	717.4	
		1 am	642.55	13.04	84	- .08	717.41	717.4	
		2 am	642.54	13.04	84	- .08	717.40	717.4	
		3 am	642.49	13.04	84	- .08	717.35	717.4	
		4 am	642.51	13.04	84	- .08	717.37	717.4	
		Avg	642.52		84	- .08	717.38	717.4	
		10 am	642.42	13.05	85	0	717.37	717.4	717.6

TABLE 2.-Electronic pressures, Bush A-5, December 1965 - March 1966 (Cont'd.)

Date			Wellhead, Psig	Baro	T, °F	Del	Psia, BH	Psia, BH	Psia, BHDW
March	10	1 am	642.41	12.99	84	-0.08	717.22	717.2	
		2 am	642.46	12.99	84	- .08	717.27	717.3	
		3 am	642.46	12.98	84	- .08	717.26	717.3	
		4 am	642.43	12.97	84	- .08	717.22	717.2	
		5 am	642.48	12.98	84	- .08	717.28	717.3	
		Avg	642.45		84	- .08	717.25	717.3	
		10 am	642.30	13.00	86	+ .08	717.28	717.3	717.9
	11	1 am	642.47	12.92	83	- .16	717.13	717.1	
		2 am	642.46	12.91	83	- .16	717.11	717.1	
		Avg	642.47		83	- .16	717.12	717.1	

TABLE 3.-Electronic pressures, Bush A-5, January 20, 1966

Time	Well Head Pressure Psig	Well Head Pressure Psia	Bottom Hole Pressure, Psia
10:13	643.05		
14	643.01		
15	643.01		
16	643.04		
17	643.05		
Avg	643.03	656.03	717.93
10:20	643.01	656.01	717.91
25	643.00	656.00	717.90
30	642.94	655.94	717.84
35	642.95	655.95	717.85
40	642.98	655.98	717.88
45	642.97	655.97	717.87
50	642.93	655.93	717.83
55	642.91	655.91	717.81
11:00	642.94	655.94	717.84
05	642.94	655.94	717.84
10	642.89	655.89	717.79
15	642.86	655.86	717.76
20	642.89	655.89	717.79
25	642.93	655.93	717.83
30	642.90	655.90	717.80
35	642.88	655.88	717.78
40	642.89	655.89	717.79
45	642.91	655.91	717.81
50	642.87	655.87	717.77
55	642.84	655.84	717.74

Time	Well Head Pressure Psig	Well Head Pressure Psia	Bottom Hole Pressure, Psia
12:00	642.84	655.84	717.74
05	642.87	655.87	717.77
10	642.86	655.86	717.76
15	642.83	655.83	717.73
20	642.85	655.85	717.75
25	642.88	655.88	717.78
30	642.85	655.85	717.75
35	642.83	655.83	717.73
40	642.81	655.81	717.71
45	642.84	655.84	717.74
50	642.85	655.85	717.75
55	642.81	655.81	717.71
1:00	642.80	655.80	717.70
05	642.79	655.79	717.69
10	642.86	655.86	717.76
15	642.86	655.86	717.76
20	642.81	655.81	717.71
25	642.79	655.79	717.69
30	642.82	655.82	717.72
35	642.85	655.85	717.75
40	642.80	655.80	717.70
45	642.78	655.78	717.68
50	642.80	655.80	717.70
55	642.85	655.85	717.75
2:00	642.85	655.85	717.75
05	642.78	655.78	717.68
10	642.77	655.77	717.67
15	642.80	655.80	717.70
20	642.82	655.82	717.72

TABLE 4.-Production-injection statistics, Cliffside reservoir, October 1965 - February 1966, mscf/day

Date	Natural Gas Withdrawn	Crude Injection			V_i/V_p	Δ V_i/V_p - 0.90
		Bivins A-6	Bivins A-3	Total		
October 1	7,317	7,380	6,344	13,724	1.88	0.98
2	7,762	7,583	6,367	13,950	1.80	.90
3	7,738	6,025	6,330	12,355	1.60	.70
4	7,848	5,786	6,315	12,101	1.54	.64
5	7,661	5,925	6,271	12,196	1.59	.70
6	7,768	5,850	6,241	12,091	1.56	.66
7	7,917	5,548	6,223	11,771	1.49	.59
8	7,830	2,981	6,260	9,241	1.18	.28
9	7,926	4,503	6,299	10,802	1.36	.46
10	7,924	6,414	6,308	12,722	1.61	.71
11	8,316	5,728	6,367	12,095	1.45	.55
12	8,229	6,321	6,395	12,716	1.55	.65
13	7,982	8,282	6,488	14,770	1.85	.95
14	6,018	8,418	6,404	14,822	2.46	1.56
15	6,712	8,394	6,379	14,773	2.20	1.30
16	8,089	8,311	6,374	14,685	1.82	.92
17	8,112	8,284	6,413	14,697	1.81	.91
18	8,013	8,299	6,424	14,723	1.84	.94
19	7,940	8,359	6,420	14,779	1.86	.96
20	7,904	8,276	6,435	14,711	1.86	.96
21	7,860	7,860	6,440	14,300	1.82	.92
22	7,943	8,063	6,404	14,467	1.82	.92
23	7,823	7,222	6,371	13,593	1.74	.84
24	7,848	7,043	6,356	13,399	1.71	.81
25	7,941	6,976	6,326	13,302	1.68	.78
26	7,814	7,737	6,316	14,053	1.80	.90
27	7,952	9,012	6,420	15,432	1.94	1.04
28	7,994	9,368	6,452	15,820	1.98	1.08
29	7,496	8,775	7,577	16,352	2.18	1.28
30	7,446	8,259	8,009	16,268	2.18	1.28
31	7,492	8,228	8,013	16,241	2.17	1.27
	240,615	225,210	201,741	426,951	1.77	0.89

TABLE 4.-Production-injection statistics, Cliffside reservoir, October 1965 - February 1966, mscf/day (Cont'd.)

Date	Natural Gas Withdrawn	Crude Injection			V_i/V_p	Δ $V_i/V_p - 0.90$
		Bivins A-6	Bivins A-3	Total		
November 1	7,504	8,024	7,953	15,977	2.13	1.23
2	7,517	7,881	8,085	15,966	2.12	1.22
3	7,424	7,268	8,045	15,313	2.06	1.16
4	7,498	7,030	8,066	15,096	2.01	1.11
5	7,552	7,614	8,059	15,673	2.08	1.18
6	7,873	7,829	8,062	15,891	2.02	1.12
7	7,546	7,796	8,019	15,815	2.10	1.20
8	7,491	8,385	8,063	16,448	2.20	1.30
9	6,704	8,726	8,113	16,839	2.51	1.61
10	7,374	8,580	8,066	16,646	2.26	1.36
11	7,551	8,296	8,108	16,404	2.12	1.22
12	7,675	7,960	8,129	16,089	2.10	1.20
13	7,725	7,969	8,104	16,073	2.08	1.18
14	7,678	8,150	8,046	16,196	2.11	1.21
15	7,813	6,311	7,926	14,237	1.82	0.92
16	8,448	5,874	7,927	13,801	1.63	.73
17	7,723	5,827	7,914	13,741	1.78	.88
18	7,756	4,887	7,907	12,794	1.65	.75
19	7,900	5,817	7,859	13,676	1.73	.83
20	7,949	6,896	7,860	14,756	1.86	.96
21	8,072	7,984	7,907	15,891	1.97	1.07
22	8,236	8,713	8,117	16,830	2.04	1.14
23	5,027	8,178	8,155	16,333	3.25	2.35
24	5,291	7,977	8,155	16,132	3.05	2.15
25	7,551	8,063	8,108	16,171	2.14	1.24
26	7,849	7,949	8,207	16,156	2.06	1.16
27	7,793	8,275	8,022	16,297	2.09	1.19
28	7,640	7,972	8,154	16,126	2.11	1.21
29	7,740	8,819	8,235	17,054	2.20	1.30
30	7,838	8,570	8,304	16,874	2.15	1.25
	225,738	229,620	241,675	471,295	2.09	1.21

TABLE 4.-Production-injection statistics, Cliffside reservoir, October 1965 - February 1966, mscf/day (Cont'd.)

Date	Natural Gas Withdrawn	Crude Injection			V_i/V_p	Δ V_i/V_p - 0.90
		Bivins A-6	Bivins A-3	Total		
December 1	7,960	7,792	8,185	16,977	2.01	1.11
2	8,130	8,156	8,150	16,306	2.01	1.11
3	7,652	8,259	8,066	16,325	2.13	1.23
4	8,561	8,234	7,943	16,177	1.89	0.99
5	9,095	8,029	7,882	15,911	1.75	.85
6	8,355	7,952	7,876	15,828	1.89	.99
7	7,932	8,062	7,842	15,904	2.01	1.11
8	8,034	8,136	7,933	16,069	2.00	1.10
9	7,840	8,298	8,102	16,400	2.09	1.19
10	8,715	8,976	8,163	17,139	1.97	1.07
11	8,727	8,737	8,201	16,938	1.94	1.04
12	8,618	8,536	8,179	16,715	1.94	1.04
13	8,634	7,524	8,176	15,700	1.82	.92
14	8,740	3,816	8,242	12,058	1.38	.48
15	8,028	6,085	8,154	14,239	1.77	.87
16	8,204	6,858	8,175	15,033	1.83	.93
17	8,246	8,027	8,132	16,159	1.96	1.06
18	8,203	8,107	8,246	16,353	1.99	1.09
19	8,250	8,324	8,236	16,560	2.01	1.11
20	8,300	8,910	8,251	17,161	2.07	1.17
21	8,146	8,382	8,275	16,657	2.04	1.14
22	7,804	8,362	7,943	16,305	2.09	1.19
23	7,927	7,703	8,082	15,785	1.99	1.09
24	7,975	5,829	8,125	13,954	1.75	.85
25	7,992	6,119	8,048	14,167	1.77	.87
26	7,901	5,902	8,100	14,002	1.77	.87
27	7,892	5,914	8,130	14,044	1.78	.88
28	8,107	6,543	8,101	16,644	2.05	1.15
29	7,517	7,986	8,058	16,044	2.13	1.23
30	7,985	8,185	8,084	16,269	2.04	1.14
31	7,983	8,154	8,068	16,222	2.03	1.13
	253,453	235,897	251,148	489,045	1.93	1.03

TABLE 4.-Production-injection statistics, Cliffside reservoir, October 1965 - February 1966, mscf/day (Cont'd.)

Date	Natural Gas Withdrawn	Crude Injection: Bivins A-6	Crude Injection: Bivins A-3	Crude Injection: Total	V_i/V_p	Δ V_i/V_p - 0.90
January 1	8,099	8,205	8,087	16,292	2.01	1.11
2	8,069	5,160	8,092	13,252	1.64	0.74
3	7,845	4,492	8,229	12,721	1.62	.72
4	8,135	4,504	8,235	12,739	1.57	.67
5	7,854	4,339	8,196	12,535	1.60	.70
6	6,849	5,574	8,206	13,780	2.01	1.11
7	7,847	6,904	8,108	15,012	1.91	1.01
8	8,263	7,614	8,102	15,716	1.90	1.00
9	8,427	8,168	8,112	16,280	1.93	1.03
10	8,566	8,085	8,118	16,203	1.89	.99
11	8,200	8,169	8,075	16,244	1.98	1.08
12	8,107	7,910	8,181	16,091	1.98	1.08
13	7,678	7,936	8,176	16,112	2.10	1.20
14	7,437	7,781	8,240	16,021	2.15	1.25
15	8,018	8,318	8,305	16,623	2.07	1.17
16	8,345	8,343	8,410	16,753	2.01	1.11
17	6,360	7,814	8,390	16,204	2.55	1.65
18	5,833	8,031	8,387	16,418	2.81	1.91
19	4,817	8,094	8,384	16,478	3.42	2.52
20	6,291	8,224	8,359	16,583	2.64	1.74
21	6,303	6,584	8,440	15,024	2.38	1.48
22	6,513	6,838	8,542	15,380	2.36	1.46
23	6,479	8,318	8,531	16,849	2.60	1.70
24	6,326	8,947	8,443	17,390	2.75	1.85
25	6,191	8,433	8,507	16,940	2.74	1.84
26	7,735	8,301	8,388	16,689	2.16	1.26
27	7,820	8,144	8,418	16,562	2.12	1.22
28	7,845	8,218	8,533	16,751	2.13	1.23
29	7,855	8,397	8,514	16,911	2.15	1.25
30	7,990	8,106	8,407	16,513	2.07	1.17
31	7,931	8,127	8,528	16,655	2.10	1.20
	230,028	232,078	257,643	489,721	2.13	1.27

TABLE 4.-Production-injection statistics, Cliffside reservoir, October 1965 - February 1966, mscf/day (Cont'd.)

Date	Natural Gas Withdrawn	Crude Injection			V_i/V_p	Δ $V_i/V_p - 0.90$
		Bivins A-6	Bivins A-3	Total		
February 1	7,252	8,411	8,632	17,043	2.35	1.45
2	7,912	8,995	8,617	17,612	2.23	1.33
3	8,038	8,565	8,562	17,127	2.13	1.23
4	8,166	8,222	8,476	16,698	2.04	1.14
5	8,149	8,236	8,470	16,706	2.05	1.15
6	8,190	8,489	8,418	16,907	2.06	1.16
7	8,150	7,609	8,527	16,136	1.98	1.08
8	8,192	5,098	8,490	13,588	1.66	0.76
9	8,157	7,571	8,446	16,017	1.96	1.06
10	7,972	7,777	8,456	16,233	2.04	1.14
11	7,988	7,700	8,465	16,165	2.02	1.12
12	8,155	7,813	8,393	16,206	1.99	1.09
13	7,894	7,398	8,572	15,970	2.02	1.12
14	8,101	6,338	8,489	14,827	1.83	.93
15	7,561	5,188	8,516	13,704	1.81	.91
16	7,921	5,525	8,520	14,045	1.77	.87
17	8,035	7,060	8,501	15,561	1.94	1.06
18	7,905	7,220	8,421	15,641	1.98	1.10
19	7,726	7,538	8,502	16,040	2.08	1.18
20	7,683	7,421	8,513	15,934	2.07	1.17
21	7,823	7,216	8,591	15,807	2.02	1.12
22	7,634	7,211	8,596	15,807	2.07	1.17
23	8,124	4,826	8,604	13,430	1.65	.75
24	8,213	7,047	8,492	15,539	1.89	.99
25	8,289	7,440	8,441	15,881	1.92	1.02
26	8,277	7,713	8,388	16,101	1.95	1.05
27	8,374	7,442	8,456	15,898	1.90	1.00
28	8,171	7,515	8,405	15,920	1.95	1.05
	224,052	204,534	237,959	442,493	1.97	1.07

TABLE 5.-Deadweight tester pressures, closed-in wells, Cliffside reservoir, October 1, 1965 - March 7, 1966

	Bush A-5		Bush A-4		Fuqua A-2		Bush A-9		Bivins A-7		Bush A-2		Average All minus
Oct.	WHP	BHP	WHP	BHP	WHP	BHP	WHP	BHP	WHP	BHP	WHP	BHP	Bush A-2
1	648.1	710.0	646.1	708.2	639.4	700.8	645.2	706.6	647.3	709.6			707.0
4	647.9	709.8	646.3	708.4	639.3	700.7	644.9	706.3	647.4	709.7	649.3	705.0	707.0
5	647.9	709.8	646.2	708.3	639.3	700.7	644.9	706.3	647.4	709.7			707.0
6	648.1	710.0	646.4	708.5	639.4	700,8	645.1	706.5	647.7	710.0			707.2
7	648.1	710.0	646.5	708.6	639.5	700.9	645.1	706.5	647.8	710.1			707.2
8	648.4	710.3	646.8	708.9	639.7	701.1	645.3	706.7	648.0	710.3			707.5
11	648.5	710.4	646.9	709.0	640.0	701.4	645.3	706.7	648.2	710.5	649.5	705.2	707.6
12	648.3	710.2	646.9	709.0	639.8	701.2	645.3	706.7	648.2	710.5			707.5
13	648.9	710.8	647.4	709.5	640.1	701.5	645.5	706.9	648.4	710.7			707.9
14	648.8	710.7	647.3	709.4	640.0	701.4	645.7	707.1	648.8	711.1			707.9
15	648.9	710.8	647.3	709.4	640.0	701.4	645.6	707.0	648.6	710.9			707.9
18	648.9	710.8	647.3	709.4	640.0	701.4	645.7	707.1	648.6	710.9	649.9	705.6	707.9
19	649.1	711.0	647.8	709.9	640.3	701.7	645.5	706.9	648.5	710.8			708.1
20	649.3	711.2	647.6	709.7	640.5	701.9	645.9	707.3	648.6	710.9			708.2
21	649.0	710.9	647.6	709.7	640.3	701.7	645.7	707.1	648.7	711.0			708.1
22	648.9	710.8	647.6	709.7	640.6	702.0	645.7	707.1	648.8	711.1			708.1
25	649.3	711.2	648.0	710.1	640.4	701.8	645.9	707.3	649.2	711.5	650.3	706.0	708.4
26	649.3	711.2	647.9	710.0	640.3	701.7	645.9	707.3	649.1	711.4			708.3
27	649.8	711.7	648.0	710.1	640.8	702.2	646.0	707.4	649.2	711.5			708.6
28	649.5	711.4	648.2	710.3	640.7	702.1	645.9	707.3	649.3	711.6			708.5
29	649.5	711.4	648.3	710.4	640.7	702.1	646.2	707.6	649.3	711.6			708.6
		710.7											707.8

TABLE 5.-Deadweight tester pressures, closed-in wells, Cliffside reservoir, October 1, 1965 - March 7, 1966 (Cont'd.)

Nov.	Bush A-5 WHP	Bush A-5 BHP	Bush A-4 WHP	Bush A-4 BHP	Fuqua A-2 WHP	Fuqua A-2 BHP	Bush A-9 WHP	Bush A-9 BHP	Bivins A-7 WHP	Bivins A-7 BHP	Bush A-2 WHP	Bush A-2 BHP	Average All minus Bush A-2
1	649.8	711.7	648.4	710.5	640.8	702.2	646.3	707.7	649.5	711.8	650.8	706.5	708.8
2	649.8	711.7	648.4	710.5	640.8	702.2	646.3	707.7	649.6	711.9			708.8
3	649.9	711.8	648.3	710.4	640.8	702.2	646.5	707.9	649.8	712.1			708.9
4	649.9	711.8			640.8	702.2	646.4	707.8	649.6	711.9			
5					640.7	702.1	646.5	707.9					
8	650.3	712.2	648.7	710.8	641.3	702.7	646.6	708.0	650.1	712.4	650.9	706.6	709.2
9	650.4	712.3	648.8	710.9	641.3	702.7	646.6	708.0	649.9	712.2			709.2
10	650.4	712.3	648.8	710.9			646.6	708.0	650.1	712.4			
12	649.8	711.7	648.3	710.4	640.5	701.9	646.2	707.6	649.5	711.8			708.7
15	650.9	712.8	649.1	711.2	641.6	703.0	646.8	708.2	650.7	713.0			709.6
16	650.8	712.7	649.4	711.5	641.5	702.9	646.9	708.3	650.7	713.0			709.7
17	650.7	712.6	649.6	711.7	641.6	703.0	647.2	708.6	650.6	712.9	651.5	707.2	709.8
18	650.9	712.8	649.6	711.7	641.6	703.0	647.3	708.7	650.7	713.0			709.8
19	650.9	712.8	649.5	711.6	641.6	703.0	647.2	708.6	650.6	712.9			709.8
22	651.2	713.1	649.8	711.9	641.7	703.1	647.2	708.6	650.8	713.1	652.0	707.7	710.0
23	651.4	713.3	650.3	712.4	642.1	703.5	647.3	708.7	651.0	713.3			710.2
24	651.6	713.5	650.0	712.1	642.0	703.4	647.7	709.1	651.2	713.4			710.3
26	651.6	713.5	650.2	712.3	642.0	703.4	647.6	709.0	651.5	713.7			710.4
29	651.5	713.4	650.3	712.4	641.8	703.2	647.7	709.1	652.3	714.5	652.5	708.2	710.5
30	651.8	713.7	650.5	712.6	642.2	703.6	647.8	709.2	651.3	713.5			710.5
		712.6											709.7

TABLE 5.-Deadweight tester pressures, closed-in wells, Cliffside reservoir, October 1, 1965 - March 7, 1966 (Cont'd.)

	Bush A-5		Bush A-4		Fuqua A-2		Bush A-9		Bivins A-7		Bush A-2		Average All minus Bush A-2
Dec.	WHP	BHP	WHP	BHP	WHP	BHP	WHP	BHP	WHP	BHP	WHP	BHP	
1	651.6	713.5	650.3	712.4	642.0	703.4	647.6	709.0	651.5	713.8			710.4
2	651.8	713.7	650.4	712.5	642.1	703.5	647.6	709.0	651.5	713.8			710.5
3	652.0	713.9	650.5	712.6	642.2	703.6	647.8	709.2	651.9	714.2			710.7
6	652.0	713.9	650.7	712.8	642.2	703.6	648.2	709.6	652.1	714.4	653.4	709.1	710.9
7	652.2	714.1	651.2	713.3	642.6	704.0	648.4	709.8	652.2	714.5			711.1
8	652.4	714.3	651.1	713.2	642.7	704.1	648.6	710.0	652.2	714.5			711.2
9	652.4	714.3	651.2	713.3	642.8	704.2	648.6	710.0	652.4	714.7			711.3
10	652.3	714.2	651.1	713.2	642.8	704.2	648.8	710.2	652.5	714.8			711.3
13	652.7	714.6	651.3	713.4	642.8	704.2	648.3	709.7	652.3	714.6	653.6	709.3	711.3
14	652.5	714.4	651.3	713.4	642.7	704.1	648.4	709.8	652.3	714.6			711.3
15	652.7	714.6	651.4	713.5	642.9	704.3	648.7	710.1	652.6	714.9			711.5
16	652.8	714.7	651.5	713.6	642.8	704.2	648.7	710.1	652.4	714.7			711.5
17	652.9	714.8	651.6	713.7	642.9	704.3	648.7	710.1	652.8	715.1			711.6
20	653.2	715.1	651.8	713.9	643.2	704.8	648.9	710.3	653.1	715.4	654.0	709.7	711.9
21	653.3	715.2	651.9	714.0	643.4	704.8	649.2	710.6	653.0	715.3			712.0
22	653.4	715.3	652.0	714.1	643.1	704.5	649.1	710.5	653.3	715.6			712.0
23	653.4	715.3	652.1	714.2	643.3	704.7	649.2	710.6	653.5	715.8			712.1
27	653.8	715.7	652.2	714.3	643.5	704.9	649.2	710.6	653.2	715.5	654.4	710.1	712.2
28	653.9	715.8	652.3	714.4	643.6	705.0	649.6	711.0	653.1	715.4			712.3
29	654.0	715.9	652.5	714.6	643.5	704.9	649.6	711.0	653.0	715.3			712.3
30	654.3	716.2	652.5	714.6	643.6	705.0	649.6	711.0	653.7	716.0			712.6
		714.7											711.5

TABLE 5.-Deadweight tester pressures, closed-in wells, Cliffside reservoir, October 1, 1965 - March 7, 1966 (Cont'd.)

Jan.	Bush A-5 WHP	Bush A-5 BHP	Bush A-4 WHP	Bush A-4 BHP	Fuqua A-2 WHP	Fuqua A-2 BHP	Bush A-9 WHP	Bush A-9 BHP	Bivins A-7 WHP	Bivins A-7 BHP	Bush A-2 WHP	Bush A-2 BHP	Average All minus Bush A-2
3	654.5	716.4	653.3	715.4	643.9	705.3	650.1	711.5	654.2	716.5	655.0	710.7	713.0
4	654.6	716.5	652.8	714.9	643.7	705.1	649.9	711.3	653.8	716.1			712.8
5	654.6	716.5	652.9	715.0	644.0	705.4	649.8	711.2	654.4	716.7			713.0
6	654.9	716.8	653.0	715.1	644.2	705.6	650.0	711.4	654.3	716.6			713.1
7	654.9	716.8	653.2	715.3	644.1	705.5	650.1	711.5	654.4	716.7			713.2
10	654.9	716.8	653.1	715.2	644.2	705.6	650.1	711.5	654.4	716.7	655.6	711.3	713.2
11	655.3	717.2	653.4	715.5	644.3	705.7	650.0	711.4	654.9	717.2			713.4
12	655.2	717.1	653.3	715.4	644.8	706.2	650.6	712.0	654.8	717.1			713.6
13	655.2	717.1	653.3	715.4	644.5	705.9	650.4	711.8	654.4	716.8			713.4
14	655.2	717.1	653.4	715.5	644.4	705.8	650.5	711.9	654.7	717.0			713.5
17	655.4	717.3	653.7	715.8	644.6	706.0	650.6	712.0	654.9	717.2			713.7
18	655.5	717.4	653.7	715.8	644.8	706.2	650.7	712.1	654.9	717.2	655.6	711.3	713.7
19	655.8	717.7	653.9	716.0	644.9	706.3	650.9	712.3	655.2	717.5			714.0
20	655.5	717.4	653.9	716.0	644.9	706.3	OPENED		655.2	717.5			714.3
24	655.8	717.7	654.0	716.1	644.8	706.2			655.1	717.4	655.7	711.4	714.4
25	655.9	717.8	654.2	716.3	645.2	706.6			655.5	717.8			714.6
26	655.9	717.8	654.2	716.3	645.4	706.8			655.7	718.0			714.7
27	655.9	717.8	654.1	716.2	645.1	706.5			655.3	717.6			714.5
28	655.9	717.8	654.2	716.3	645.3	706.7			655.5	717.8			714.6
31	656.1	718.0	654.3	716.4	645.4	706.8			655.6	717.9			714.8
		717.3											713.8

TABLE 5.-Deadweight tester pressures, closed-in wells, Cliffside reservoir, October 1, 1965 - March 7, 1966 (Cont'd.)

Feb.	Bush A-5 WHP	Bush A-5 BHP	Bush A-4 WHP	Bush A-4 BHP	Fuqua A-2 WHP	Fuqua A-2 BHP	Bivins A-7 WHP	Bivins A-7 BHP	Bush A-2 WHP	Bush A-2 BHP	Average All minus Bush A-2
1	656.2	718.1	654.4	716.5	645.6	707.0	655.9	718.2			715.0
2	655.9	717.8	654.4	716.5	654.4	706.8	655.7	718.0	656.9	712.6	714.8
3	656.0	717.9	654.5	716.6	645.5	706.9	655.8	718.1			714.9
4	656.0	717.9	654.6	716.7	645.6	707.0	655.8	718.1			714.9
7	656.0	717.9	654.9	717.0	645.4	706.8	656.0	718.3	657.3	713.0	715.0
8	655.9	717.8	654.9	717.0	645.3	706.7	656.1	718.4			715.0
9	656.6	718.4	655.4	717.5	646.2	707.6	656.9	719.2			715.7
10	656.5	718.4	655.3	717.4							
11	656.5	718.4	655.3	717.4	646.0	707.4	656.8	719.1			715.6
14	655.9	717.8	655.2	717.3	645.8	707.2	656.9	719.2	657.8	713.5	715.4
15	655.8	717.7	655.2	717.3							
16	656.0	717.9	655.6	717.7	646.4	707.8	657.1	719.4	657.9	713.6	715.7
17	655.8	717.7	655.5	717.6	646.1	707.5	656.9	719.2	657.8	713.5	715.5
18	655.8	717.7	655.6	717.7	646.4	707.8	657.1	719.4	658.1	713.8	715.6
21	655.9	717.8	656.0	718.3	646.5	707.9	657.2	719.5	658.3	714.0	715.9
23	655.8	717.7	656.1	718.4	646.8	708.2	657.2	719.5	658.3	714.0	716.0
24	655.7	717.6	656.0	718.3	646.9	708.3	657.4	719.7	658.4	714.1	716.0
25	655.9	717.8	656.0	718.3	647.1	708.5	657.7	720.0	658.8	714.5	716.2
28	655.6	717.5	656.4	718.7	647.1	708.5	657.7	720.0	659.1	714.8	716.2
		717.9									715.5

TABLE 5.-Deadweight tester pressures, closed-in wells, Cliffside reservoir, October 1, 1965 - March 7, 1966 (Cont'd.)

Mar.	Bush A-5 WHP	Bush A-5 BHP	Bush A-4 WHP	Bush A-4 BHP	Fuqua A-2 WHP	Fuqua A-2 BHP	Bivins A-7 WHP	Bivins A-7 BHP	Bush A-2 WHP	Bush A-2 BHP	Average All minus Bush A-2
1	655.9	717.8	656.3	718.4	646.8	708.2	657.8	720.1	659.0	714.7	716.1
2	655.8	717.7	656.5	718.6	646.9	708.3	657.8	720.1	658.9	714.6	716.2
3	655.6	717.5	656.6	718.7	647.1	708.5	657.8	720.1	659.1	714.8	716.2
4	655.6	717.5	656.8	718.9	647.3	708.7	658.2	720.5	659.5	715.2	716.4
7	655.6	717.5	657.0	719.1	647.4	708.8	658.0	720.3	659.6	715.3	716.4
8	655.7	717.6	656.9	719.0	647.2	708.6	658.0	720.3	659.6	715.3	716.4
9	655.7	717.6	656.8	718.9	647.4	708.8	658.4	720.7	659.7	715.4	716.5
10	656.0	717.9	657.0	719.1	647.5	708.9	658.1	720.4	659.6	715.3	716.6

TABLE 6.-Pressure maintenance-volumetric material balance correlation summary, closed-in wells, Cliffside reservoir, October 1965 - February 1966

	Well						Material Balance Entire Reservoir		Deadweight Measurements All Wells	
	Average Slope, Pressure-Time									
Month	Bush A-5	Bush A-4	Fuq. A-2	Bush A-9	Biv. A-7	All	Delta	Delta Running Average	Average Pressure psia	Running Average Pressure psia
October	0.06	0.08	0.05	0.04	0.07	0.060	0.89	0.89	707.8	707.8
November	.07	.08	.05	.05	.07	.065	1.21	1.05	709.7	708.8
December	.08	.07	.05	.06	.06	.066	1.03	1.04	711.5	709.7
January	.06	.05	.06	.06	.06	.060	1.27	1.10	713.8	710.7
February	-.02	.08	.07	--	.07	.052	1.07	1.09	715.5	711.7
							1.09			

Month	Bush A-5	Bush A-4	Fuq. A-2	Bush A-9	Biv. A-7	All	Delta Change	Calculated Running Average Pressure, psia
October	0.0625	0.0771	0.0533	0.0402	0.0716	0.0602*	0.00	(707.8)
November	.0711	.0799	.0504	.0534	.0743	.0649	.16	710.9
December	.0828	.0715	.0524	.0618	.0620	.0662	- .01	710.7
January	.0553	.0527	.0559	.0576**	.0561	.0604**	.06	711.9
February	-.0167	.0794	.0653	--	.0747	.0515	- .01	711.7

* Plotted least square averages; not arithmetic averages.

** These values apply from January 1-19.

TABLE 6.-Pressure maintenance-volumetric material balance correlation summary, closed-in wells, Cliffside reservoir, October 1965 - February 1966

	Well						Material Balance Entire Reservoir		Deadweight Measurements All Wells	
	Average Slope, Pressure-Time									
Month	Bush A-5	Bush A-4	Fuq. A-2	Bush A-9	Biv. A-7	All	Delta	Delta Running Average	Average Pressure psia	Running Average Pressure psia
October	0.06	0.08	0.05	0.04	0.07	0.060	0.22	0.22	707.8	707.8
November	.07	.08	.05	.05	.07	.065	.54	.38	709.7	708.8
December	.08	.07	.05	.06	.06	.066	.38	.38	711.5	709.7
January	.06	.05	.06	.06	.06	.073	.58	.43	713.8	710.7
February	-.02	.08	.07	--	.07	.052	.42	.43	715.5	711.7

Month	Bush A-5	Bush A-4	Fuq. A-2	Bush A-9	Biv. A-7	All	Delta Change	Calculated Running Average Pressure, psia
October	0.0625	0.0771	0.0533	0.0402	0.0716	0.0602	0	(707.8)
November	.0711	.0799	.0504	.0534	.0743	.0649	0.16	710.7
December	.0828	.0715	.0524	.0618	.0620	.0662	0	710.7
January	.0553	.0527	.0559	.0576	.0561	.0730	0.05	711.6
February	-.0167	.0794	.0653	--	.0747	.0515	0	711.6

REFERENCES

1. Carroll, A. J., and S. E. Churchwell. Compressibility of Cliffside Gas. Helium Research Center Memorandum Report No. 18, June 1963, 5 pp.

2. Guereca, R. A., and H. P. Richardson. Pressure-Capacitance Measurement Research Proposal for Cliffside. Helium Research Center Memorandum Report No. 76, December 1965, pp. 8-9.

3. Holmes, R. A. Results of Cliffside Field Drilling Program, Fiscal Year 1964. Helium Activity Internal Report, April 1964, pp. 21-22.

4. Miller, J. E., and L. Stroud. Supercompressibility Factors for Helium-Nitrogen Mixtures. U. S. Bureau of Mines Report of Investigations 6192, 1963, pp. 4-5.

5. Pirson, S. J. Oil Reservoir Engineering, 2d ed. McGraw-Hill Book Co., Inc., New York, 1958, p. 363.